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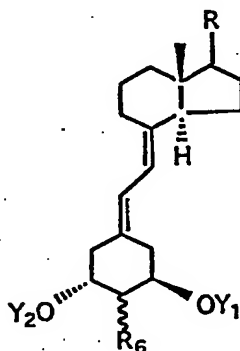
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(54) Title: 2-ALKYL-19-NOR-VITAMIN D COMPOUNDS



(I)

(57) Abstract

This invention provides a novel class of vitamin D related compounds, namely, the 2-alkyl-19-nor-vitamin D derivatives, as well as a general method for their chemical synthesis. The compounds have formula (I), where Y₁ and Y₂, which may be the same or different, are each selected from the group consisting of hydrogen and a hydroxy-protecting group, R₆ is selected from the group consisting of alkyl, hydroxyalkyl and fluoroalkyl, and where the group R represents any of the typical side chains known for vitamin D type compounds. These 2-substituted compounds are characterized by low intestinal calcium transport activity and high bone calcium mobilization activity resulting in novel therapeutic agents for the treatment of diseases where bone formation is desired, particularly low bone turnover osteoporosis. These compounds also exhibit pronounced activity in arresting the proliferation of undifferentiated cells and inducing their differentiation to the monocyte thus evaluating use as anti-cancer agents and for the treatment of diseases such as psoriasis.

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2-ALKYL-19-NOR-VITAMIN D COMPOUNDS

CROSS-REFERENCE TO RELATED APPLICATIONS

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STATEMENT REGARDING FEDERALLY
SPONSERED RESEARCH OR DEVELOPMENT

BACKGROUND OF THE INVENTION

10 This patent invention relates to vitamin D compounds, and more particularly to vitamin D derivatives substituted at the carbon 2 position.

The natural hormone, $1\alpha,25$ -dihydroxyvitamin D_3 and its analog in ergosterol series, i.e. $1\alpha,25$ -dihydroxyvitamin D_2 are known to be highly potent regulators of calcium homeostasis in animals and humans, and more recently their activity in cellular differentiation has been established, 15 Ostrem et al., Proc. Natl. Acad. Sci. USA, 84, 2610 (1987). Many structural analogs of these metabolites have been prepared and tested, including 1α -hydroxyvitamin D_3 , 1α -hydroxyvitamin D_2 , various side chain homologated vitamins and fluorinated analogs. Some of these compounds exhibit an interesting separation of activities in cell differentiation and calcium 20 regulation. This difference in activity may be useful in the treatment of a variety of diseases as renal osteodystrophy, vitamin D-resistant rickets, osteoporosis, psoriasis, and certain malignancies.

Recently, a new class of vitamin D analogs has been discovered, i.e. the so called 19-nor-vitamin D compounds, which are characterized by the 25 replacement of the A-ring exocyclic methylene group (carbon 19), typical of the vitamin D system, by two hydrogen atoms. Biological testing of such 19-nor-analogs (e.g., $1\alpha,25$ -dihydroxy-19-nor-vitamin D_3) revealed a selective activity profile with high potency in inducing cellular differentiation, and very low calcium mobilizing activity. Thus, these

compounds are potentially useful as therapeutic agents for the treatment of malignancies, or the treatment of various skin disorders. Two different methods of synthesis of such 19-nor-vitamin D analogs have been described (Perlman et al., Tetrahedron Lett. 31, 1823 (1990); Perlman et al., Tetrahedron Lett. 32, 7663 (1991), and DeLuca et al., U.S. Pat. No. 5,086,191).

In U.S. Pat. No. 4,666,634, 2 β -hydroxy and alkoxy (e.g., ED-71) analogs of 1 α ,25-dihydroxyvitamin D₃ have been described and examined by Chugai group as potential drugs for osteoporosis and as antitumor agents. See also Okano et al., Biochem. Biophys. Res. Commun. 163, 1444 (1989). Other 2-substituted (with hydroxyalkyl, e.g., ED-120, and fluoroalkyl groups) A-ring analogs of 1 α ,25-dihydroxyvitamin D₃ have also been prepared and tested (Miyamoto et al., Chem. Pharm. Bull. 41, 1111 (1993); Nishii et al., Osteoporosis Int. Suppl. 1, 190 (1993); Posner et al., J. Org. Chem. 59, 7855 (1994), and J. Org. Chem. 60, 4617 (1995)).

Recently, 2-substituted analogs of 1 α ,25-dihydroxy-19-norvitamin D₃ have also been synthesized, i.e. compounds substituted at 2-position with hydroxy or alkoxy groups (DeLuca et al., U.S. Pat. No. 5,536,713), which exhibit interesting and selective activity profiles. All these studies indicate that binding sites in vitamin D receptors can accomodate different substituents at C-2 in the synthesized vitamin D analogs.

In a continuing effort to explore the 19-nor class of pharmacologically important vitamin D compounds, their analogs which are characterized by the presence of an alkyl (particularly methyl) substituent at the carbon 2 (C-2), i.e. 2-alkyl-19-nor-vitamin D compounds, and particularly 2-methyl-19-nor-vitamin D compounds, have now been synthesized and tested. Such vitamin D analogs seemed interesting targets because the relatively small alkyl (particularly

methoxy) group at C-2 should not interfere with vitamin D receptor. On the other hand it is obvious that a change of conformation of the cyclohexanediol ring A can be expected for these new analogs.

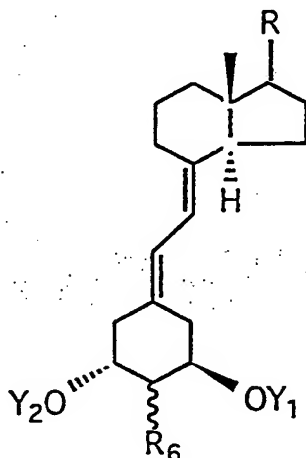
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SUMMARY OF THE INVENTION

A class of 1α -hydroxylated vitamin D compounds not known heretofore are the 19-nor-vitamin D analogs having an alkyl (particularly methyl) group at the 2-position, i.e. 2-alkyl-19-nor-vitamin D compounds, particularly 2-methyl-19-nor-vitamin D compounds.

10 Structurally these novel analogs are characterized by the general formula I shown below:

15



I

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where Y_1 and Y_2 , which may be the same or different, are each selected from the group consisting of hydrogen and a hydroxy-protecting group, R_6 is selected from the group consisting of alkyl, hydroxyalkyl and fluoroalkyl, and where the group R represents any of the typical side chains known for vitamin D type compounds.

More specifically R can represent a saturated or unsaturated hydrocarbon radical of 1 to 35 carbons, that may be straight-chain, branched or cyclic and that may contain one or more additional

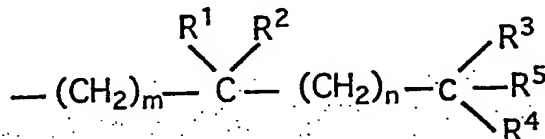
substituents, such as hydroxy- or protected-hydroxy groups, fluoro, carbonyl, ester, epoxy, amino or other heteroatomic groups. Preferred side chains of this type are represented by the structure below

5



where the stereochemical center (corresponding to C-20 in steroid numbering) may have the R or S configuration, (i.e. either the natural configuration about carbon 20 or the 20-epi configuration), and where Z is selected from Y, -OY, -CH₂OY, -C≡CY and -CH=CHY, where the double bond may have the cis or trans geometry, and where Y is selected from hydrogen, methyl, -COR⁵ and a radical of the structure:

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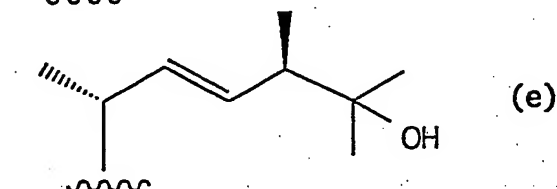
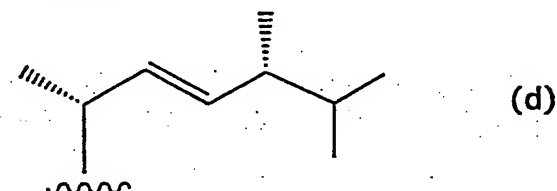
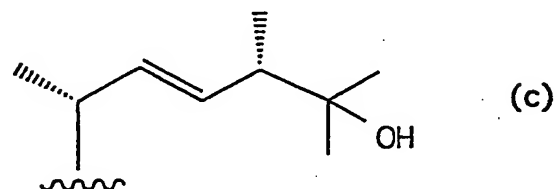
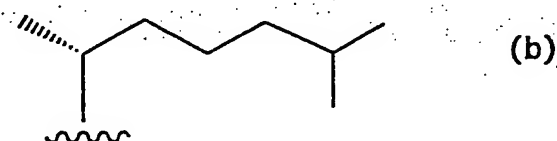
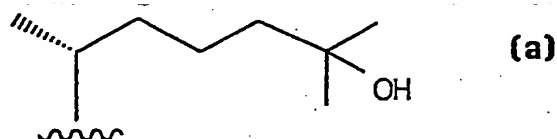


where m and n, independently, represent the integers from 0 to 5, where R¹ is selected from hydrogen, deuterium, hydroxy, protected hydroxy, fluoro, trifluoromethyl, and C₁₋₅-alkyl, which may be straight chain or branched and, optionally, bear a hydroxy or protected-hydroxy substituent, and where each of R², R³, and R⁴, independently, is selected from deuterium, deuterioalkyl, hydrogen, fluoro, trifluoromethyl and C₁₋₅ alkyl, which may be straight-chain or branched, and optionally, bear a hydroxy or protected-hydroxy substituent, and where R¹ and R², taken together, represent an oxo group, or an alkylidene group, =CR²R³, or the group -(CH₂)_p-, where p is an integer from 2 to 5, and where R³ and R⁴, taken together, represent an oxo group, or the group -(CH₂)_q-, where q is an integer from 2 to 5, and where R⁵ represents hydrogen, hydroxy, protected

hydroxy, or C₁₋₅ alkyl and wherein any of the CH-groups at positions 20, 22, or 23 in the side chain may be replaced by a nitrogen atom, or where any of the groups -CH(CH₃)-, -CH(R³)-, or -CH(R²)- at positions 20, 22, and 23, respectively, may be replaced by an oxygen or sulfur atom.

5 The wavy lines to the substituents at C-2 and at C-20 indicate that the carbon 2 and carbon 20 may have either the R or S configuration.

Specific important examples of side chains with natural 20*R*-configuration are the structures represented by formulas (a), (b), (c), (d) and (e) below. i.e. the side chain as it occurs in 25-hydroxyvitamin D₃ (a);
10 vitamin D₃ (b); 25-hydroxyvitamin D₂ (c); vitamin D₂ (d); and the C-24 epimer of 25-hydroxyvitamin D₂ (e):



The above novel compounds exhibit a desired, and highly advantageous, pattern of biological activity. These compounds are characterized by little, if any intestinal calcium transport activity, as compared to that of $1\alpha,25$ -dihydroxyvitamin D_3 , while exhibiting relatively high activity, as compared to $1\alpha,25$ -dihydroxyvitamin D_3 , in their ability to mobilize calcium from bone. Hence, these compounds are highly specific in their calcemic activity. Their preferential activity on mobilizing calcium from bone and reduced intestinal calcium transport activity allows the in vivo administration of these compounds for the treatment of metabolic bone diseases where bone loss is a major concern. Because of their preferential calcemic activity on bone, these compounds would be preferred therapeutic agents for the treatment of diseases where bone formation is desired, such as osteoporosis, especially low bone turnover osteoporosis, steroid induced osteoporosis, senile osteoporosis or postmenopausal osteoporosis, as well as osteomalacia and renal osteodystrophy. The treatment may be transdermal, oral or parenteral. The compounds may be present in a composition in an amount from about $0.1\mu\text{g/gm}$ to about $50\mu\text{g/gm}$ of the composition, and may be administered in dosages of from about $0.1\mu\text{g/day}$ to about $50\mu\text{g/day}$.

The compounds of the invention are also especially suited for treatment and prophylaxis of human disorders which are characterized by an imbalance in the immune system, e.g. in autoimmune diseases, including multiple sclerosis, diabetes mellitus, host versus graft reaction, and rejection of transplants; and additionally for the treatment of inflammatory diseases, such as rheumatoid arthritis and asthma, as well as the improvement of bone fracture healing and improved bone grafts. Acne, alopecia, skin conditions such as dry skin (lack of dermal hydration),

undue skin slackness (insufficient skin firmness), insufficient sebum secretion and wrinkles, and hypertension are other conditions which may be treated with the compounds of the invention.

The above compounds are also characterized by high cell
5 differentiation activity. Thus, these compounds also provide therapeutic agents for the treatment of psoriasis, or as an anti-cancer agent, especially against leukemia, colon cancer, breast cancer and prostate cancer. The compounds may be present in a composition to treat psoriasis in an amount from about 0.01 μ g/gm to about 100 μ g/gm of the
10 composition, and may be administered topically, transdermally, orally or parenterally in dosages of from about 0.01 μ g/day to about 100 μ g/day.

This invention also provides novel intermediate compounds formed during the synthesis of the end products.

This invention also provides a novel synthesis for the production of
15 the end products of structure I.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a graph illustrating the relative activity of a mixture of
2 α and 2 β -methyl-19-nor-20S-1 α ,25-dihydroxyvitamin D₃, a mixture of
20 2 α and 2 β -methyl-19-nor-1 α ,25-dihydroxyvitamin D₃ and 1 α ,25-dihydroxyvitamin D₃ to compete for binding of [3H]-1,25-(OH)₂-D₃ to the vitamin D pig intestinal nuclear receptor; and

Figure 2 is a graph illustrating the percent HL-60 cell
differentiation as a function of the concentration of a mixture of 2 α and
25 2 β -methyl-19-nor-20S-1 α ,25-dihydroxyvitamin D₃, a mixture of 2 α and 2 β -methyl-19-nor-1 α ,25-dihydroxyvitamin D₃ and 1 α ,25-dihydroxyvitamin D₃.

DETAILED DESCRIPTION OF THE INVENTION

As used in the description and in the claims, the term "hydroxy-protecting group" signifies any group commonly used for the temporary protection of hydroxy functions, such as for example, alkoxycarbonyl, acyl, alkylsilyl or alkylarylsilyl groups (hereinafter referred to simply as "silyl" groups), and alkoxyalkyl groups. Alkoxycarbonyl protecting groups are alkyl-O-CO- groupings such as methoxycarbonyl, ethoxycarbonyl, propoxycarbonyl, isopropoxycarbonyl, butoxycarbonyl, isobutoxycarbonyl, tert-butoxycarbonyl, benzyloxycarbonyl or allyloxycarbonyl. The term "acyl" signifies an alkanoyl group of 1 to 6 carbons, in all of its isomeric forms, or a carboxyalkanoyl group of 1 to 6 carbons, such as an oxalyl, malonyl, succinyl, glutaryl group, or an aromatic acyl group such as benzoyl, or a halo, nitro or alkyl substituted benzoyl group. The word "alkyl" as used in the description or the claims, denotes a straight-chain or branched alkyl radical of 1 to 10 carbons, in all its isomeric forms. Alkoxyalkyl protecting groups are groupings such as methoxymethyl, ethoxymethyl, methoxyethoxymethyl, or tetrahydrofuranyl and tetrahydropyranyl. Preferred silyl-protecting groups are trimethylsilyl, triethylsilyl, t-butyldimethylsilyl, dibutylmethylsilyl, diphenylmethylsilyl, phenyldimethylsilyl, diphenyl-t-butylysilyl and analogous alkylated silyl radicals. The term "aryl" specifies a phenyl-, or an alkyl-, nitro- or halo-substituted phenyl group.

A "protected hydroxy" group is a hydroxy group derivatised or protected by any of the above groups commonly used for the temporary or permanent protection of hydroxy functions, e.g. the silyl, alkoxyalkyl, acyl or alkoxycarbonyl groups, as previously defined. The terms "hydroxyalkyl", "deuteroalkyl" and "fluoroalkyl" refer to an alkyl radical substituted by one or more hydroxy, deuterium or fluoro groups respectively.

It should be noted in this description that the term "24-homo" refers to the addition of one methylene group and the term "24-dihomo"

refers to the addition of two methylene groups at the carbon 24 position in the side chain. Likewise, the term "trihomo" refers to the addition of three methylene groups. Also, the term "26,27-dimethyl" refers to the addition of a methyl group at the carbon 26 and 27 positions so that for example R³ and R⁴ are ethyl groups. Likewise, the term "26,27-diethyl" refers to the addition of an ethyl group at the 26 and 27 positions so that R³ and R⁴ are propyl groups.

In the following lists of compounds, the particular substituent attached at the carbon 2 position should be added to the nomenclature. For example, if a methyl group is the alkyl substituent, the term "2-methyl" should precede each of the named compounds. If an ethyl group is the alkyl substituent, the term "2-ethyl" should precede each of the named compounds, and so on. In addition, if the methyl group attached at the carbon 20 position is in its epi or unnatural configuration, the term "20(S)" or "20-epi" should be included in each of the following named compounds. The named compounds could also be of the vitamin D₂ type if desired.

Specific and preferred examples of the 2-alkyl-compounds of structure I when the side chain is unsaturated are:

- 19-nor-24-homo-1,25-dihydroxy-22-dehydrovitamin D₃;
- 19-nor-24-dihomo-1,25-dihydroxy-22-dehydrovitamin D₃;
- 19-nor-24-trihomo-1,25-dihydroxy-22-dehydrovitamin D₃;
- 19-nor-26,27-dimethyl-24-homo-1,25-dihydroxy-22-dehydrovitamin D₃;
- 19-nor-26,27-dimethyl-24-dihomo-1,25-dihydroxy-22-dehydrovitamin D₃;
- 19-nor-26,27-dimethyl-24-trihomo-1,25-dihydroxy-22-dehydrovitamin D₃;

19-nor-26,27-diethyl-24-homo-1,25-dihydroxy-22-dehydrovitamin D₃;

19-nor-26,27-diethyl-24-dihomo-1,25-dihydroxy-22-dehydrovitamin D₃;

5 19-nor-26,27-diethyl-24-trihomo-1,25-dihydroxy-22-dehydrovitamin D₃;

19-nor-26,27-dipropoyl-24-homo-1,25-dihydroxy-22-dehydrovitamin D₃;

10 19-nor-26,27-dipropyl-24-dihomo-1,25-dihydroxy-22-dehydrovitamin D₃; and

19-nor-26,27-dipropyl-24-trihomo-1,25-dihydroxy-22-dehydrovitamin D₃.

Specific and preferred examples of the 2-alkyl-compounds of structure I when the side chain is saturated are:

15 19-nor-24-homo-1,25-dihydroxyvitamin D₃;

19-nor-24-dihomo-1,25-dihydroxyvitamin D₃;

19-nor-24-trihomo-1,25-dihydroxyvitamin D₃;

19-nor-26,27-dimethyl-24-homo-1,25-dihydroxyvitamin D₃;

19-nor-26,27-dimethyl-24-dihomo-1,25-dihydroxyvitamin D₃;

20 19-nor-26,27-dimethyl-24-trihomo-1,25-dihydroxyvitamin D₃;

19-nor-26,27-diethyl-24-homo-1,25-dihydroxyvitamin D₃;

19-nor-26,27-diethyl-24-dihomo-1,25-dihydroxyvitamin D₃;

19-nor-26,27-diethyl-24-trihomo-1,25-dihydroxyvitamin D₃;

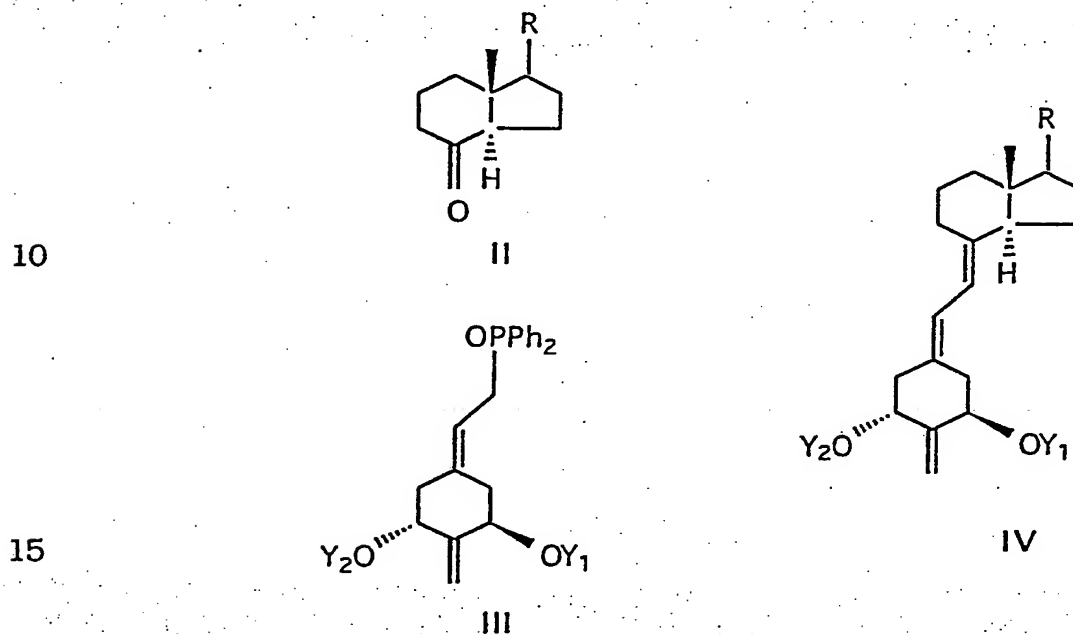
19-nor-26,27-dipropyl-24-homo-1,25-dihydroxyvitamin D₃;

25 19-nor-26,27-dipropyl-24-dihomo-1,25-dihydroxyvitamin D₃; and

19-nor-26,27-dipropyl-24-trihomo-1,25-dihydroxyvitamin D₃.

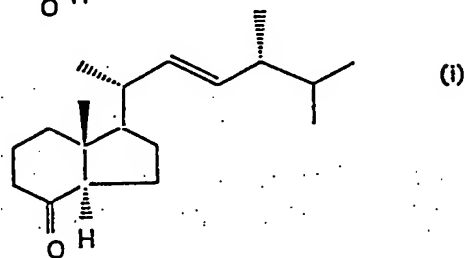
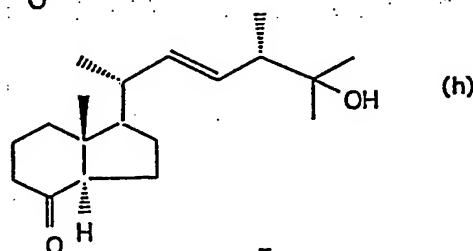
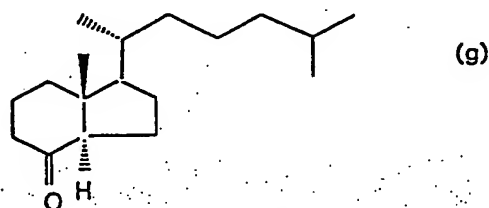
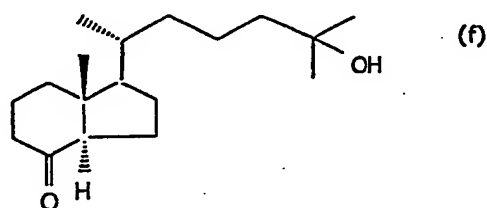
The preparation of 1 α -hydroxy-2-alkyl-19-nor-vitamin D compounds, particularly 1 α -hydroxy-2-methyl-19-nor-vitamin D

compounds, having the basic structure I can be accomplished by a common general method, i.e. the condensation of a bicyclic Windaus-Grundmann type ketone II with the allylic phosphine oxide III to the corresponding 2-methylene-19-nor-vitamin D analogs IV followed by a selective reduction of the exomethylene group at C-2 in the latter compounds:



In the structures II, III, and IV groups Y_1 and Y_2 and R represent groups defined above; Y_1 and Y_2 are preferably hydroxy-protecting groups, it being also understood that any functionalities in R that might be sensitive, or that interfere with the condensation reaction, be suitable protected as is well-known in the art. The process shown above represents an application of the convergent synthesis concept, which has been applied effectively for the preparation of vitamin D compounds [e.g. Lythgoe et al., J. Chem. Soc. Perkin Trans. I, 590 (1978); Lythgoe, Chem. Soc. Rev. 9, 449 (1983); Toh et al., J. Org. Chem. 48, 1414 (1983); Baggiolini et al., J. Org. Chem. 51, 3098 (1986); Sardina et al., J. Org. Chem. 51, 1264 (1986); J. Org. Chem. 51, 1269 (1986); DeLuca et al., U.S. Pat. No. 5,086,191; DeLuca et al., U.S. Pat. No. 5,536,713].

Hydrindanones of the general structure II are known, or can be prepared by known methods. Specific important examples of such known bicyclic ketones are the structures with the side chains (a), (b), (c) and (d) described above, i.e. 25-hydroxy Grundmann's ketone (f) [Baggiolini et al., J. Org. Chem, 51, 3098 (1986)]; Grundmann's ketone (g) [Inhoffen et al., Chem. Ber. 90, 664 (1957)]; 25-hydroxy Windaus ketone (h) [Baggiolini et al., J. Org. Chem., 51, 3098 (1986)] and Windaus ketone (i) [Windaus et al., Ann., 524, 297 (1936)]:



For the preparation of the required phosphine oxides of general structure III, a new synthetic route has been developed starting from methyl quinate derivative 1, easily obtained from commercial (1R,3R,4S,5R)-(-)-quinic acid as described by Perlman et al., Tetrahedron Lett. 32, 7663 (1991) and DeLuca et al., U.S. Pat. No. 5,086,191. The overall process of transformation of the starting methyl ester 1 into the desired

A-ring synthons, is summarized by the SCHEME I. Thus, the secondary 4-hydroxyl group of 1 was oxidized with RuO₄ (a catalytic method with RuCl₃ and NaIO₄ as co-oxidant). Use of such a strong oxidant was necessary for an effective oxidation process of this very hindered hydroxyl. However, other more commonly used oxidants can also be applied (e.g. pyridinium dichromate), although the reactions usually require much longer time for completion. Second step of the synthesis comprises the Wittig reaction of the sterically hindered 4-keto compound 2 with ylide prepared from methyltriphenylphosphonium bromide and *n*-butyllithium. Other bases can be also used for the generation of the reactive methylenephosphorane, like *t*-BuOK, NaNH₂, NaH, K/HMPT, NaN(TMS)₂, etc. For the preparation of the 4-methylene compound 3 some described modifications of the Wittig process can be used, e.g. reaction of 2 with activated methylenetriphenylphosphorane [Corey et al., Tetrahedron Lett. 26, 555 (1985)]. Alternatively, other methods widely used for methylenation of unreactive ketones can be applied, e.g. Wittig-Horner reaction with the PO-ylid obtained from methyldiphenylphosphine oxide upon deprotonation with *n*-butyllithium [Schosse et al., Chimia 30, 197 (1976)], or reaction of ketone with sodium methylsulfinate [Corey et al., J. Org. Chem. 28, 1128 (1963)] and potassium methylsulfinate [Greene et al., Tetrahedron Lett. 3755 (1976)]. Reduction of the ester 3 with lithium aluminum hydride or other suitable reducing agent (e.g. DIBALH) provided the diol 4 which was subsequently oxidized by sodium periodate to the cyclohexanone derivative 5. The next step of the process comprises the Peterson reaction of the ketone 5 with methyl(trimethylsilyl)acetate. The resulting allylic ester 6 was treated with diisobutylaluminum hydride and the formed allylic alcohol 7 was in turn transformed to the desired A-ring phosphine oxide 8. Conversion of 7 to 8 involved 3 steps, namely, *in situ* tosylation with *n*-butyllithium and *p*-toluenesulfonyl chloride, followed by reaction with diphenylphosphine lithium salt and oxidation with hydrogen peroxide.

Several 2-methylene-19-nor-vitamin D compounds of the general structure IV may be synthesized using the A-ring synthon 8 and the appropriate Windaus-Grundmann ketone II having the desired side chain structure. Thus, for example, Wittig-Horner coupling of the lithium
5 phosphinoxy carbanion generated from 8 and *n*-butyllithium with the protected 25-hydroxy Grundmann's ketone 9 prepared according to published procedure [Sicinski et al., J. Med. Chem. 37, 3730 (1994)] gave the expected protected vitamin compound 10. This, after deprotection with AG 50W-X4 cation exchange resin afforded 1 α ,25-dihydroxy-2-
10 methylene-19-nor-vitamin D₃ (11).

The final step of the process was the selective homogeneous catalytic hydrogenation of the exomethylene unit at carbon 2 in the vitamin 11 performed efficiently in the presence of tris(triphenylphosphine)rhodium(I) chloride [Wilkinson's catalyst,
15 (Ph₃P)₃RhCl]. Such reduction conditions allowed to reduce only C(2)=CH₂ unit leaving C(5)-C(8) butadiene moiety unaffected. The isolated material is an epimeric mixture (ca. 1:1) of 2-methyl-19-nor-vitamins 12 and 13 differing in configuration at C-2. The mixture can be used without separation or, if desired, the individual 2 α - and 2 β -isomers can be
20 separated by an efficient HPLC system.

The C-20 epimerization was accomplished by the analogous coupling of the phosphine oxide 8 with protected (20*S*)-25-hydroxy Grundmann's ketone 15 (SCHEME II) and provided 19-nor-vitamin 16 which after hydrolysis of the hydroxy-protecting groups gave (20*S*)-1 α ,25-
25 dihydroxy-2-methylene-19-nor-vitamin D₃ (17). Hydrogenation of 17 using Wilkinson's catalyst provided the expected mixture of the 2-methyl-19-nor-vitamin D analogs 18 and 19.

As noted above, other 2-methyl-19-nor-vitamin D analogs may be synthesized by the method disclosed herein. For example, 1 α -hydroxy-2-

methylene-19-nor-vitamin D₃ can be obtained by providing the Grundmann's ketone (g); subsequent reduction of the A-ring exomethylene group in the formed compound can give the corresponding epimeric mixture of 1 α -hydroxy-2-methyl-19-nor-vitamin D₃ compounds.

- 5 This invention is described by the following illustrative examples. In these examples specific products identified by Arabic numerals (e.g. 1, 2, 3, etc) refer to the specific structures so identified in the preceding description and in the SCHEME I and SCHEME II.

10

EXAMPLE 1

Preparation of 1 α ,25-dihydroxy-2 α - and 1 α ,25-dihydroxy-2 β -methyl-19-nor-vitamin D₃ (12 and 13).

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Referring first to SCHEME I the starting methyl quinic acid derivative 1 was obtained from commercial (-)-quinic acid as described previously [Perlman et al., Tetrahedron Lett. 32, 7663 (1991) and DeLuca et al., U.S. Pat. No. 5,086,191]. 1: mp. 82-82.5 °C (from hexane), ¹H NMR (CDCl₃) δ 0.098, 0.110, 0.142, and 0.159 (each 3H, each s, 4 x SiCH₃), 0.896 and 0.911 (9H and 9H, each s, 2 x Si-t-Bu), 1.820 (1H, dd, J = 13.1, 10.3 Hz), 2.02 (1H, ddd, J = 14.3, 4.3, 2.4 Hz), 2.09 (1H, dd, J = 14.3, 2.8 Hz), 2.19 (1H, ddd, J = 13.1, 4.4, 2.4 Hz), 2.31 (1H, d, J = 2.8 Hz, OH), 3.42 (1H, m; after D₂O dd, J = 8.6, 2.6 Hz), 3.77 (3H, s), 4.12 (1H, m), 4.37 (1H, m), 4.53 (1H, br s, OH).

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(a) Oxidation of 4-hydroxy group in methyl quinic acid derivative 1.

(3R,5R)-3,5-Bis[(*tert*-butyldimethylsilyl)oxy]-1-hydroxy-4-oxocyclohexanecarboxylic Acid Methyl Ester (2). To a stirred mixture of ruthenium(III) chloride hydrate (434 mg, 2.1 mmol) and sodium

periodate (10.8 g, 50.6 mmol) in water (42 mL) was added a solution of methyl quinate 1 (6.09 g, 14 mmol) in $\text{CCl}_4/\text{CH}_3\text{CN}$ (1:1, 64 mL). Vigorous stirring was continued for 8 h. Few drops of 2-propanol were added, the mixture was poured into water and extracted with chloroform. The organic
5 extracts were combined, washed with water, dried (MgSO_4) and evaporated to give a dark oily residue (ca. 5 g) which was purified by flash chromatography. Elution with hexane/ethyl acetate (8:2) gave pure, oily 4-ketone 2 (3.4 g, 56%): ^1H NMR (CDCl_3) δ 0.054, 0.091, 0.127, and 0.132 (each 3H, each s, 4 x SiCH_3), 0.908 and 0.913 (9H and 9H, each s, 2 x Si-
10 Bu), 2.22 (1H, dd, $J = 13.2, 11.7$ Hz), 2.28 (1H, ~ dt, $J = 14.9, 3.6$ Hz), 2.37 (1H, dd, $J = 14.9, 3.2$ Hz), 2.55 (1H, ddd, $J = 13.2, 6.4, 3.4$ Hz), 3.79 (3H, s), 4.41 (1H, t, $J \sim 3.5$ Hz), 4.64 (1H, s, OH), 5.04 (1H, dd, $J = 11.7, 6.4$ Hz); MS m/z (relative intensity) no M^+ , 375 ($\text{M}^+ - t\text{-Bu}$, 32), 357 ($\text{M}^+ - t\text{-Bu} - \text{H}_2\text{O}$, 47), 243 (31), 225 (57), 73 (100).

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(b) Wittig reaction of the 4-ketone 2.

(3R,5R)-3,5-Bis[(*tert*-butyldimethylsilyl)oxy]-1-hydroxy-4-methylenecyclohexanecarboxylic Acid Methyl Ester (3). To the
20 methyltriphenylphosphonium bromide (2.813 g, 7.88 mmol) in anhydrous THF (32 mL) at 0 °C was added dropwise *n*-BuLi (2.5 M in hexanes, 6.0 mL, 15 mmol) under argon with stirring. Another portion of $\text{MePh}_3\text{P}^+\text{Br}^-$ (2.813 g, 7.88 mmol) was then added and the solution was stirred at 0 °C for 10 min and at room temperature for 40 min. The orange-red mixture was again
25 cooled to 0 °C and a solution of 4-ketone 2 (1.558 g, 3.6 mmol) in anhydrous THF (16 + 2 mL) was syphoned to reaction flask during 20 min. The reaction mixture was stirred at 0 °C for 1 h and at room temperature for 3 h. The mixture was then carefully poured into brine cont. 1% HCl and extracted with ethyl acetate and benzene. The combined

organic extracts were washed with diluted NaHCO_3 and brine, dried (MgSO_4) and evaporated to give an orange oily residue (ca. 2.6 g) which was purified by flash chromatography. Elution with hexane/ethyl acetate (9:1) gave pure 4-methylene compound 3 as a colorless oil (368 mg, 24%): ^1H NMR (CDCl_3) δ 0.078, 0.083, 0.092, and 0.115 (each 3H, each s, 4 x SiCH_3), 0.889 and 0.920 (9H and 9H, each s, 2 x Si-t-Bu), 1.811 (1H, dd, $J = 12.6$, 11.2 Hz), 2.10 (2H, m), 2.31 (1H, dd, $J = 12.6$, 5.1 Hz), 3.76 (3H, s), 4.69 (1H, t, $J = 3.1$ Hz), 4.78 (1H, m), 4.96 (2H, m; after D_2O 1H, br s), 5.17 (1H, t, $J = 1.9$ Hz); MS m/z (relative intensity) no M^+ , 373 ($\text{M}^+ - \text{t-Bu}$, 57), 355 ($\text{M}^+ - \text{t-Bu} - \text{H}_2\text{O}$, 13), 341 (19), 313 (25), 241 (33), 223 (37), 209 (56), 73 (100).

(c) Reduction of ester group in the 4-methylene compound 3.

[(3R,5R)-3,5-Bis[(*tert*-butyldimethylsilyl)oxy]-1-hydroxy-4-methylenecyclohexyl]methanol (4). (i) To a stirred solution of the ester 3 (90 mg, 0.21 mmol) in anhydrous THF (8 mL) lithium aluminum hydride (60 mg, 1.6 mmol) was added at 0 °C under argon. The cooling bath was removed after 1 h and the stirring was continued at 6 °C for 12 h and at room temperature for 6 h. The excess of the reagent was decomposed with saturated aq. Na_2SO_4 , and the mixture was extracted with ethyl acetate and ether, dried (MgSO_4) and evaporated. Flash chromatography of the residue with hexane/ethyl acetate (9:1) afforded unreacted substrate (12 mg) and a pure, crystalline diol 4 (35 mg, 48% based on recovered ester 3): ^1H NMR ($\text{CDCl}_3 + \text{D}_2\text{O}$) δ 0.079, 0.091, 0.100, and 0.121 (each 3H, each s, 4 x SiCH_3), 0.895 and 0.927 (9H and 9H, each s, 2 x Si-t-Bu), 1.339 (1H, t, $J \sim 12$ Hz), 1.510 (1H, dd, $J = 14.3$, 2.7 Hz), 2.10 (2H, m), 3.29 and 3.40 (1H and 1H, each d, $J = 11.0$ Hz), 4.66 (1H, t, $J \sim 2.8$ Hz), 4.78 (1H, m), 4.92 (1H, t, $J = 1.7$ Hz), 5.13 (1H, t, $J = 2.0$ Hz); MS m/z (relative intensity)

no M⁺, 345 (M⁺ - *t*-Bu, 8), 327 (M⁺ - *t*-Bu - H₂O, 22), 213 (28), 195 (11), 73 (100).

(ii) Diisobutylaluminum hydride (1.5 M in toluene, 2.0 mL, 3 mmol) was added to a solution of the ester 3 (215 mg, 0.5 mmol) in anhydrous ether (3 mL) at -78 °C under argon. The mixture was stirred at -78 °C for 3 h and at -24 °C for 1.5 h, diluted with ether (10 mL) and quenched by the slow addition of 2N potassium sodium tartrate. The solution was warmed to room temperature and stirred for 15 min, then poured into brine and extracted with ethyl acetate and ether. The organic extracts were combined, washed with diluted (ca. 1%) HCl, and brine, dried (MgSO₄) and evaporated. The crystalline residue was purified by flash chromatography. Elution with hexane/ethyl acetate (9:1) gave crystalline diol 4 (43 mg, 24%).

15 (d) Cleavage of the vicinal diol 4.

(3R,5R)-3,5-Bis[(*tert*-butyldimethylsilyl)oxy]-4-methylenecyclohexanone (5). Sodium periodate saturated water (2.2 mL) was added to a solution of the diol 4 (146 mg, 0.36 mmol) in methanol (9 mL) at 0 °C. The solution was stirred at 0 °C for 1 h, poured into brine and extracted with ether and benzene. The organic extracts were combined, washed with brine, dried (MgSO₄) and evaporated. An oily residue was dissolved in hexane (1 mL) and applied on a silica Sep-Pak cartridge. Pure 4-methylenecyclohexanone derivative 5 (110 mg, 82%) was eluted with hexane/ethyl acetate (95:5) as a colorless oil: ¹H NMR (CDCl₃) δ 0.050 and 0.069 (6H and 6H, each s, 4 x SiCH₃), 0.881 (18H, s, 2 x Si-*t*-Bu), 2.45 (2H, ddd, J = 14.2, 6.9, 1.4 Hz), 2.64 (2H, ddd, J = 14.2, 4.6, 1.4 Hz), 4.69 (2H, dd, J = 6.9, 4.6 Hz), 5.16 (2H, s); MS m/z (relative intensity) no M⁺, 355 (M⁺ - Me, 3), 313 (M⁺ - *t*-Bu, 100), 73 (76).

(e) Preparation of the allylic ester 6.

[(3'R,5'R)-3',5'-Bis[(*tert*-butyldimethylsilyl)oxy]-4'-methylenecyclohexylidene]acetic Acid Methyl Ester (6). To a solution of diisopropylamine (37 μ L, 0.28 mmol) in anhydrous THF (200 μ L) was added *n*-BuLi (2.5 M in hexanes, 113 μ L, 0.28 mmol) under argon at -78 °C with stirring, and methyl(trimethylsilyl)acetate (46 μ L, 0.28 mmol) was then added. After 15 min, the keto compound 5 (49 mg, 0.132 mmol) in anhydrous THF (200 + 80 μ L) was added dropwise. The solution was stirred at -78 °C for 2 h and the reaction mixture was quenched with saturated NH₄Cl, poured into brine and extracted with ether and benzene. The combined organic extracts were washed with brine, dried (MgSO₄) and evaporated. The residue was dissolved in hexane (1 mL) and applied on a silica Sep-Pak cartridge. Elution with hexane and hexane/ethyl acetate (98:2) gave a pure allylic ester 6 (50 mg, 89%) as a colorless oil: ¹H NMR (CDCl₃) δ 0.039, 0.064, and 0.076 (6H, 3H, and 3H, each s, 4 x SiCH₃), 0.864 and 0.884 (9H and 9H, each s, 2 x Si-*t*-Bu), 2.26 (1H, dd, *J* = 12.8, 7.4 Hz), 2.47 (1H, dd, *J* = 12.8, 4.2 Hz), 2.98 (1H, dd, *J* = 13.3, 4.0 Hz), 3.06 (1H, dd, *J* = 13.3, 6.6 Hz), 3.69 (3H, s), 4.48 (2H, m), 4.99 (2H, s), 5.74 (1H, s); MS *m/z* (relative intensity) 426 (M⁺, 2), 411 (M⁺ - Me, 4), 369 (M⁺ - *t*-Bu, 100), 263 (69).

(f) Reduction of the allylic ester 6.

2-[(3'R,5'R)-3',5'-Bis[(*tert*-butyldimethylsilyl)oxy]-4'-methylenecyclohexylidene]ethanol (7). Diisobutylaluminum hydride (1.5 M in toluene, 1.6 mL, 2.4 mmol) was slowly added to a stirred solution of the allylic ester 6 (143 mg, 0.33 mmol) in toluene/methylene chloride (2:1, 5.7 mL) at -78 °C under argon. Stirring was continued at -78 °C for 1

h and at -46 °C (cyclohexanone/dry ice bath) for 25 min. The mixture was quenched by the slow addition of potassium sodium tartrate (2N, 3 mL), aq. HCl (2N, 3 mL) and H₂O (12 mL), and then diluted with methylene chloride (12 mL) and extracted with ether and benzene. The organic extracts were combined, washed with diluted (ca. 1%) HCl, and brine, dried (MgSO₄) and evaporated. The residue was purified by flash chromatography. Elution with hexane/ethyl acetate (9:1) gave crystalline allylic alcohol 7 (130 mg, 97%): ¹H NMR (CDCl₃) δ 0.038, 0.050, and 0.075 (3H, 3H, and 6H, each s, 4 x SiCH₃), 0.876 and 0.904 (9H and 9H, each s, 2 x Si-*t*-Bu), 2.12 (1H, dd, J = 12.3, 8.8 Hz), 2.23 (1H, dd, J = 13.3, 2.7 Hz), 2.45 (1H, dd, J = 12.3, 4.8 Hz), 2.51 (1H, dd, J = 13.3, 5.4 Hz), 4.04 (1H, m; after D₂O dd, J = 12.0, 7.0 Hz), 4.17 (1H, m; after D₂O dd, J = 12.0, 7.4 Hz), 4.38 (1H, m), 4.49 (1H, m), 4.95 (1H, br s), 5.05 (1H, t, J = 1.7 Hz), 5.69 (1H, ~ t, J = 7.2 Hz); MS m/z (relative intensity) 398 (M⁺, 2), 383 (M⁺ - Me, 2), 365 (M⁺ - Me - H₂O, 4), 341 (M⁺ - *t*-Bu, 78), 323 (M⁺ - *t*-Bu - H₂O, 10), 73 (100).

(g) Conversion of the allylic alcohol 7 into phosphine oxide 8.

[2-[(3'R,5'R)-3',5'-Bis[(*tert*-butyldimethylsilyl)oxy]-4'-methylenecyclohexylidene]ethyl]diphenylphosphine Oxide (8). To the allylic alcohol 7 (105 mg, 0.263 mmol) in anhydrous THF (2.4 mL) was added *n*-BuLi (2.5 M in hexanes, 105 µL, 0.263 mmol) under argon at 0 °C. Freshly recrystallized tosyl chloride (50.4 mg, 0.264 mmol) was dissolved in anhydrous THF (480 µL) and added to the allylic alcohol-BuLi solution. The mixture was stirred at 0 °C for 5 min and set aside at 0 °C. In another dry flask with air replaced by argon, *n*-BuLi (2.5 M in hexanes, 210 µL, 0.525 mmol) was added to Ph₂PH (93 µL, 0.534 mmol) in anhydrous THF (750 µL) at 0 °C with stirring. The red solution was syphoned under argon pressure to the solution of tosylate until the orange color persisted (ca.

1/2 of the solution was added). The resulting mixture was stirred an additional 30 min at 0 °C, and quenched by addition of H₂O (30 µl). Solvents were evaporated under reduced pressure and the residue was redissolved in methylene chloride (2.4 mL) and stirred with 10% H₂O₂ at 0 °C for 1 h.

- 5 The organic layer was separated, washed with cold aq. sodium sulfite and H₂O, dried (MgSO₄) and evaporated. The residue was subjected to flash chromatography. Elution with benzene/ethyl acetate (6:4) gave semicrystalline phosphine oxide 8 (134 mg, 87%): ¹H NMR (CDCl₃) δ 0.002, 0.011, and 0.019 (3H, 3H, and 6H, each s, 4 x SiCH₃), 0.855 and 0.860 (9H and 9H, each s, 2 x Si-*t*-Bu), 2.0 - 2.1 (3H, br m), 2.34 (1H, m), 3.08 (1H, m), 3.19 (1H, m), 4.34 (2H, m), 4.90 and 4.94 (1H and 1H, each s), 5.35 (1H, ~ q, J = 7.4 Hz), 7.46 (4H, m), 7.52 (2H, m), 7.72 (4H, m); MS m/z (relative intensity) no M⁺, 581 (M⁺ - 1, 1), 567 (M⁺ - Me, 3), 525 (M⁺ - *t*-Bu, 100), 450 (10), 393 (48).
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(h) Wittig-Horner coupling of protected 25-hydroxy Grundmann's ketone 9 with the phosphine oxide 8.

- 1 α,25-Dihydroxy-2-methylene-19-nor-vitamin D₃ (11). To a solution of phosphine oxide 8 (33.1 mg, 56.8 µmol) in anhydrous THF (450 µL) at 0 °C was slowly added *n*-BuLi (2.5 M in hexanes, 23 µL, 57.5 µmol) under argon with stirring. The solution turned deep orange. The mixture was cooled to -78 °C and a precooled (-78 °C) solution of protected hydroxy ketone 9 (9.0 mg, 22.8 µmol), prepared according to published procedure [Sicinski et al., J. Med. Chem. 37, 3730 (1994)], in anhydrous THF (200 + 100 µL) was slowly added. The mixture was stirred under argon at -78 °C for 1 h and at 0 °C for 18 h. Ethyl acetate was added, and the organic phase was washed with brine, dried (MgSO₄) and evaporated. The residue was dissolved in hexane and applied on a silica Sep-Pak cartridge,
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and washed with hexane/ethyl acetate (99:1, 20 mL) to give 19-nor-vitamin derivative 10 (13.5 mg, 78%). The Sep-Pak was then washed with hexane/ethyl acetate (96:4, 10 mL) to recover some unchanged C,D-ring ketone 9 (2 mg), and with ethyl acetate (10 mL) to recover

5 diphenylphosphine oxide (20 mg). For analytical purpose a sample of protected vitamin 10 was further purified by HPLC (6.2 mm x 25 cm Zorbax-Sil column, 4 mL/min) using hexane/ethyl acetate (99.9:0.1) solvent system. Pure compound 10 was eluted at R_V 26 mL as a colorless oil: UV (in hexane) λ_{max} 244, 253, 263 nm; 1H NMR ($CDCl_3$) δ 0.025, 0.049, 10 0.066, and 0.080 (each 3H, each s, 4 x $SiCH_3$), 0.546 (3H, s, 18- H_3), 0.565 (6H, q, $J = 7.9$ Hz, 3 x $SiCH_2$), 0.864 and 0.896 (9H and 9H, each s, 2 x $Si-t-Bu$), 0.931 (3H, d, $J = 6.0$ Hz, 21- H_3), 0.947 (9H, t, $J = 7.9$ Hz, 3 x $SiCH_2CH_3$), 1.188 (6H, s, 26- and 27- H_3), 2.00 (2H, m), 2.18 (1H, dd, $J = 12.5, 8.5$ Hz, 4 β -H), 2.33 (1H, dd, $J = 13.1, 2.9$ Hz, 10 β -H), 2.46 (1H, dd, $J = 12.5, 4.5$ Hz, 15 4 α -H), 2.52 (1H, dd, $J = 13.1, 5.8$ Hz, 10 α -H), 2.82 (1H, br d, $J = 12$ Hz, 9 β -H), 4.43 (2H, m, 1 β - and 3 α -H), 4.92 and 4.97 (1H and 1H, each s, = CH_2), 5.84 and 6.22 (1H and 1H, each d, $J = 11.0$ Hz, 7- and 6-H); MS m/z (relative intensity) 758 (M^+ , 17), 729 ($M^+ - Et$, 6), 701 ($M^+ - t-Bu$, 4), 626 (100), 494 (23), 366 (50), 73 (92).

20 Protected vitamin 10 (4.3 mg) was dissolved in benzene (150 μ L) and the resin (AG 50W-X4, 60 mg; prewashed with methanol) in methanol (800 μ L) was added. The mixture was stirred at room temperature under argon for 17 h, diluted with ethyl acetate/ether (1:1, 4 mL) and decanted. The resin was washed with ether (8 mL) and the combined organic phases 25 washed with brine and saturated $NaHCO_3$, dried ($MgSO_4$) and evaporated. The residue was purified by HPLC (6.2 mm x 25 cm Zorbax-Sil column, 4 mL/min) using hexane/2-propanol (9:1) solvent system. Analytically pure 2-methylene-19-nor-vitamin 11 (2.3 mg, 97%) was collected at R_V 29 mL (1 $\alpha,25$ -dihydroxyvitamin D_3 was eluted at R_V 52 mL in the same system)

as a white solid: UV (in EtOH) λ_{\max} 243.5, 252, 262.5 nm; ^1H NMR (CDCl_3) δ 0.552 (3H, s, 18- H_3), 0.941 (3H, d, J = 6.4 Hz, 21- H_3), 1.222 (6H, s, 26- and 27- H_3), 2.01 (2H, m), 2.27 - 2.36 (2H, m), 2.58 (1H, m), 2.80 - 2.88 (2H, m), 4.49 (2H, m, 1 β - and 3 α -H), 5.10 and 5.11 (1H and 1H, each s, = CH_2), 5.89 and 6.37 (1H and 1H, each d, J = 11.3 Hz, 7- and 6-H); MS m/z (relative intensity) 416 (M^+ , 83), 398 (25), 384 (31), 380 (14), 351 (20), 313 (100).

(i) Hydrogenation of 2-methylene-19-nor-vitamin 11.

10 1 α ,25-Dihydroxy-2 α - and 1 α ,25-Dihydroxy-2 β -methyl-19-nor-vitamin D₃ (12 and 13). Tris(triphenylphosphine)rhodium(I) chloride (2.3 mg, 2.5 μmol) was added to dry benzene (2.5 mL) presaturated with hydrogen. The mixture was stirred at room temperature until a homogeneous solution was formed (ca. 45 min). A solution of vitamin 11
15 (1.0 mg, 2.4 μmol) in dry benzene (0.5 mL) was then added and the reaction was allowed to proceed under a continuous stream of hydrogen for 3 h. Benzene was removed under vacuum, and hexane/ethyl acetate (1:1, 2 mL) was added to the residue. The mixture was applied on a silica Sep-Pak and both 2-methyl vitamins were eluted with the same solvent system (20
20 mL). Further purification was achieved by HPLC (6.2 mm x 25 cm Zorbax-Sil column, 4 mL/min) using hexane/2-propanol (9:1) as a solvent system. The mixture (ca. 1:1) of 2-methyl-19-nor-vitamins (2 α - and 2 β -epimers 12 and 13; 0.80 mg, 80%) gave a single peak at R_V 33 mL.

12 and 13: UV (in EtOH) λ_{\max} 243, 251, 261.5 nm; ^1H NMR (CDCl_3) δ 0.536
25 and 0.548 (3H and 3H, each s, 2 x 18- H_3), 0.937 (6H, d, J = 6.3 Hz, 2 x 21- H_3), 1.133 and 1.144 (3H and 3H, each d, J ~ 6 Hz, 2 x 2- CH_3), 1.219 [12H, s, 2 x (26- and 27- H_3)], 2.60 (1H, dd, J = 13.0, 4.6 Hz), 2.80 (3H, m), 3.08 (1H, dd, J = 12.6, 4.0 Hz), 3.51 (1H, dt, J = 4.6, 10.2 Hz), 3.61 (1H, dt, J = 4.5, 9.1

Hz), 3.90 (1H, narr m), 3.96 (1H, narr m), 5.82, 5.87, 6.26, and 6.37 (each 1H, each d, $J = 11.2$ Hz); MS m/z (relative intensity) 418 (M^+ , 100), 400 (25), 385 (15), 289 (30), 245 (25).

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EXAMPLE 2

Preparation of (20S)-1 α ,25-dihydroxy-2 α - and (20S)-1 α ,25-dihydroxy-2 β -methyl-19-nor-vitamin D₃ (18 and 19).

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SCHEME II illustrates the preparation of protected (20S)-25-hydroxy Grundmann's ketone 15, its coupling with phosphine oxide 8 (obtained as described in Example 1) and selective hydrogenation of exomethylene group in 2-methylene compound 17.

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(a) Silylation of hydroxy ketone 14.

(20S)-25-[(Triethylsilyl)oxy]-des-A,B-cholestan-8-one (15). A solution of the ketone 14 (Tetrionics, Inc.; 56 mg, 0.2 mmol) and imidazole (65 mg, 0.95 mmol) in anhydrous DMF (1.2 mL) was treated with
20 triethylsilyl chloride (95 μ L, 0.56 mmol), and the mixture was stirred at room temperature under argon for 4 h. Ethyl acetate was added and water, and the organic layer was separated. The ethyl acetate layer was washed with water and brine, dried ($MgSO_4$) and evaporated. The residue was
25 passed through a silica Sep-Pak cartridge in hexane/ethyl acetate (9:1), and after evaporation, purified by HPLC (9.4 mm x 25 cm Zorbax-Sil column, 4 mL/min) using hexane/ethyl acetate (9:1) solvent system. Pure protected hydroxy ketone 15 (55 mg, 70%) was eluted at R_V 35 mL as a colorless oil: 1H NMR ($CDCl_3$) δ 0.566 (6H, q, $J = 7.9$ Hz, 3 x $SiCH_2$), 0.638

(3H, s, 18-H₃), 0.859 (3H, d, J = 6.0 Hz, 21-H₃), 0.947 (9H, t, J = 7.9 Hz, 3 x SiCH₂CH₃), 1.196 (6H, s, 26- and 27-H₃), 2.45 (1H, dd, J = 11.4, 7.5 Hz, 14 α -H).

- 5 (b) Wittig-Horner coupling of protected (20S)-25-hydroxy Grundmann's ketone 15 with the phosphine oxide 8.

(20S)-1 α ,25-Dihydroxy-2-methylene-19-nor-vitamin D₃ (17). To a solution of phosphine oxide 8 (15.8 mg, 27.1 μ mol) in anhydrous THF (200 μ L) at 0 $^{\circ}$ C was slowly added *n*-BuLi (2.5 M in hexanes, 11 μ L, 27.5 μ mol) under argon with stirring. The solution turned deep orange. The mixture was cooled to -78 $^{\circ}$ C and a precooled (-78 $^{\circ}$ C) solution of protected hydroxy ketone 15 (8.0 mg, 20.3 μ mol) in anhydrous THF (100 μ L) was slowly added. The mixture was stirred under argon at -78 $^{\circ}$ C for 1 h and at 15 0 $^{\circ}$ C for 18 h. Ethyl acetate was added, and the organic phase was washed with brine, dried (MgSO₄) and evaporated. The residue was dissolved in hexane and applied on a silica Sep-Pak cartridge, and washed with with hexane/ethyl acetate (99.5:0.5, 20 mL) to give 19-nor-vitamin derivative 16 (7 mg, 45%) as a colorless oil. The Sep-Pak was then washed with 20 hexane/ethyl acetate (96:4, 10 mL) to recover some unchanged C,D-ring ketone 15 (4 mg), and with ethyl acetate (10 mL) to recover diphenylphosphine oxide (9 mg). For analytical purpose a sample of protected vitamin 16 was further purified by HPLC (6.2 mm x 25 cm Zorbax-Sil column, 4 mL/min) using hexane/ethyl acetate (99.9:0.1) 25 solvent system.

16: UV (in hexane) λ_{max} 244, 253.5, 263 nm; ¹H NMR (CDCl₃) δ 0.026, 0.049, 0.066, and 0.080 (each 3H, each s, 4 x SiCH₃), 0.541 (3H, s, 18-H₃), 0.564 (6H, q, J = 7.9 Hz, 3 x SiCH₂), 0.848 (3H, d, J = 6.5 Hz, 21-H₃), 0.864 and 0.896 (9H and 9H, each s, 2 x Si-t-Bu), 0.945 (9H, t, J = 7.9 Hz, 3 x

SiCH₂CH₃), 1.188 (6H, s, 26- and 27-H₃), 2.15 - 2.35 (4H, br m), 2.43 - 2.53 (3H, br m), 2.82 (1H, br d, J = 12.9 Hz, 9β-H), 4.42 (2H, m, 1β- and 3α-H), 4.92 and 4.97 (1H and 1H, each s, =CH₂), 5.84 and 6.22 (1H and 1H, each d, J = 11.1 Hz, 7- and 6-H); MS m/z (relative intensity) 758 (M⁺, 33), 729 (M⁺ - Et, 7), 701 (M⁺ - *t*-Bu, 5), 626 (100), 494 (25), 366 (52), 75 (82), 73 (69).

Protected vitamin 16 (5.0 mg) was dissolved in benzene (160 μL) and the resin (AG 50W-X4, 70 mg; prewashed with methanol) in methanol (900 μL) was added. The mixture was stirred at room temperature under argon for 19 h, diluted with ethyl acetate/ether (1:1, 4 mL) and decanted. The resin was washed with ether (8 mL) and the combined organic phases washed with brine and saturated NaHCO₃, dried (MgSO₄) and evaporated. The residue was purified by HPLC (6.2 mm x 25 cm Zorbax-Sil column, 4 mL/min) using hexane/2-propanol (9:1) solvent system. Analytically pure 2-methylene-19-nor-vitamin 17 (2.6 mg, 95%) was collected at R_v 28 mL [(20*R*)-analog was eluted at R_v 29 mL and 1α,25-dihydroxyvitamin D₃ at R_v 52 mL in the same system] as a white solid: UV (in EtOH) λ_{max} 243.5, 252.5, 262.5 nm; ¹H NMR (CDCl₃) δ 0.551 (3H, s, 18-H₃), 0.858 (3H, d, J = 6.6 Hz, 21-H₃), 1.215 (6H, s, 26- and 27-H₃), 1.95 - 2.04 (2H, m), 2.27 - 2.35 (2H, m), 2.58 (1H, dd, J = 13.3, 3.7 Hz), 2.80 - 2.87 (2H, m), 4.49 (2H, m, 1β- and 3α-H), 5.09 and 5.11 (1H and 1H, each s, =CH₂), 5.89 and 6.36 (1H and 1H, each d, J = 11.3 Hz, 7- and 6-H); MS m/z (relative intensity) 416 (M⁺, 100), 398 (26), 380 (13), 366 (21), 313 (31).

(c) Hydrogenation of 2-methylene-19-nor-vitamin 17.

(20*S*)-1α,25-Dihydroxy-2α- and 1α,25-Dihydroxy-2β-methyl-19-nor-vitamin D₃ (18 and 19).

Tris(triphenylphosphine)rhodium(I) chloride (2.3 mg, 2.5 μmol) was added

to dry benzene (2.5 mL) presaturated with hydrogen. The mixture was stirred at room temperature until a homogeneous solution was formed (ca. 45 min). A solution of vitamin 17 (1.0 mg, 2.4 μ mol) in dry benzene (0.5 mL) was then added and the reaction was allowed to proceed under a continuous stream of hydrogen for 3 h. Benzene was removed under vacuum, and hexane/ethyl acetate (1:1, 2 mL) was added to the residue. The mixture was applied on a silica Sep-Pak and both 2-methyl vitamins were eluted with the same solvent system (20 mL). Further purification was achieved by HPLC (6.2 mm x 25 cm Zorbax-Sil column, 4 mL/min) using hexane/2-propanol (9:1) as a solvent system. The mixture (ca. 1:1) of 2-methyl-19-nor-vitamins (2 α - and 2 β -epimers 18 and 19; 0.43 mg, 43%) gave a single peak at R_V 31 mL.

18 and 19: UV (in EtOH) λ_{max} 243, 251, 261 nm; 1H NMR ($CDCl_3$) δ 0.534 and 0.546 (3H and 3H, each s, 2 x 18- H_3), 0.852 and 0.857 (3H and 3H, each d, J = 6.5 Hz, 2 x 21- H_3), 1.133 (3H, d, J = 6.7 Hz, 2- CH_3), 1.143 (3H, d, J = 6.5 Hz, 2- CH_3), 1.214 [12H, s, 2 x (26- and 27- H_3)], 2.60 (1H, dd, J = 12.7, 4.5 Hz), 2.80 (3H, m), 3.08 (1H, dd, J = 13.1, 4.3 Hz), 3.51 (1H, br m; after D_2O dt, J = 4.5, 10.0 Hz), 3.61 (1H, br m; after D_2O dt, J = 4.4, 9.2 Hz), 3.90 (1H, narr m), 3.96 (1H, narr m), 5.82, 5.87, 6.26, and 6.37 (each 1H, each d, J = 11.3 Hz); MS m/z (relative intensity) 418 (M^+ , 100), 400 (45), 385 (20), 289 (38), 245 (47).

BIOLOGICAL ACTIVITY OF 2-METHYL-SUBSTITUTED

19-NOR-1,25-(OH) $_2$ D $_3$ COMPOUNDS AND THEIR 20S-ISOMERS

25 The introduction of a methyl group to the 2-position of 19-nor-1,25-(OH) $_2$ D $_3$ or its 20S-isomer had little or no effect on binding to the porcine intestinal vitamin D receptor. All compounds bound equally well to the porcine receptor including the standard 1,25-(OH) $_2$ D $_3$ (Figure 1). It might be expected from these results that all of these compounds would

have equivalent biological activity. Surprisingly, however, the 2-methyl substitutions produced highly selective analogs with their primary action on bone. When given for 7 days in a chronic mode, the most potent compounds tested were a mixture of the S and R isomers of 2-methyl 19-nor-20S-1,25-(OH)₂D₃ (Table 1). When given at 130 pmol/day, the activity of this mixture of compounds on bone calcium mobilization (serum calcium) was much higher than that of the native hormone, possibly as high as 10 or 100 times higher. Under identical conditions, twice the dose of 1,25-(OH)₂D₃ gave a serum calcium value of 7.2 mg/100 ml, while a mixture of 2-methyl-(S and R)-19-nor-20S-1,25-(OH)₂D₃ gave a value of 9.6 mg/100 ml of serum calcium at the 130 pmol dose. When given at 260 pmol/day, this mixture produced the astounding value of 12.2 mg/100 ml of serum calcium at the expense of bone. To show its selectivity, these compounds produced no significant change in intestinal calcium transport at 130 pmol dose level while having a strong bone calcium mobilizing activity. At the higher dose, the 2-methyl-20S mixture did produce an intestinal transport response but gave an enormous bone mobilization response. A mixture of the S and R isomers of 2-methyl-19-nor-1,25-(OH)₂D₃ also had strong bone calcium mobilization at both dose levels but also showed no intestinal calcium transport activity. Thus, the 2-methyl-S and R derivatives given as a mixture showed strong preferential bone calcium mobilizing activity especially when the side chain was in the 20S-configuration. These results illustrate that the 2-methyl and the 20S-2-methyl derivatives of 19-nor-1,25-(OH)₂D₃ are selective for the mobilization of calcium from bone. Table 2 illustrates the response of both intestine and serum calcium to a single large dose of the various compounds; again, supporting the conclusions derived from Table 1.

The results in Figure 2 illustrate that a mixture of the S and R derivatives of 2-methyl-19-nor-20S-1,25-(OH)₂D₃ is extremely potent in inducing differentiation of HL-60 cells to the monocyte. The 2-methyl-S and R compounds had activity similar to 1,25-(OH)₂D₃. These results illustrate the potential of the 2-methyl-19-nor-20S-1,25-(OH)₂D₃ compounds as anti-cancer agents, especially against leukemia, colon cancer, breast cancer and prostate cancer, or as agents in the treatment of psoriasis.

Competitive binding of the analogs to the porcine intestinal receptor was carried out by the method described by Dame et al (Biochemistry 25, 4523-4534, 1986).

The differentiation of HL-60 promyelocytic into monocytes was determined as described by Ostrem et al (J. Biol. Chem. 262, 14164-14171, 1987).

TABLE 1

Response of Intestinal Calcium Transport and Serum Calcium (Bone Calcium Mobilization) Activity to Chronic Doses of 2-Methyl Derivatives of 19-Nor-1,25-(OH)₂D₃ and its 20S Isomers

Group	Dose (pmol/day/7 days)	Intestinal Calcium Transport (S/M)	Serum Calcium (mg/100 ml)
Vitamin D Deficient	Vehicle	5.5 ± 0.2	5.1 ± 0.16
1,25-(OH) ₂ D ₃ Treated	260	6.2 ± 0.4	7.2 ± 0.5
2-Methyl (S and R) 19-Nor-1,25-(OH) ₂ D ₃	130 260	5.0 ± 0.3 5.3 ± 0.6	6.1 ± 0.1 6.7 ± 0.4
2-Methyl (S and R) 19-Nor-20S-1,25-(OH) ₂ D ₃	130 260	5.0 ± 0.9 6.9 ± 0.5	9.6 ± 0.1 12.2 ± 0.3

Male weanling rats were obtained from Sprague Dawley Co. (Indianapolis, IN) and fed a 0.47% calcium, 0.3% phosphorus vitamin D-

deficient diet for 1 week and then given the same diet containing 0.02% calcium, 0.3% phosphorus for 2 weeks. During the last week they were given the indicated dose of compound by intraperitoneal injection in 0.1 ml 95% propylene glycol and 5% ethanol each day for 7 days. The control animals received only the 0.1ml of 95% propylene glycol, 5% ethanol. Twenty-four hours after the last dose, the rats were sacrificed and intestinal calcium transport was determined by everted sac technique as previously described and serum calcium determined by atomic absorption spectrometry on a model 3110 Perkin Elmer instrument (Norwalk, CT). There were 5 rats per group and the values represent mean \pm SEM.

TABLE 2

Response of Intestinal Calcium Transport and Serum Calcium (Bone Calcium Mobilization) Activity to a Single Dose of the 2-Methyl-Derivatives of 19-Nor-1,25-(OH)₂D₃ and its 20S Isomers

Group	Intestinal Calcium Transport (S/M)	Serum Calcium (mg/100 ml)
-D Control	4.2 \pm 0.3	4.7 \pm 0.1
1,25-(OH) ₂ D ₃	5.8 \pm 0.3	5.7 \pm 0.2
2-Methyl (S and R mixture)-19-Nor-1,25-(OH) ₂ D ₃	3.6 \pm 0.4	5.4 \pm 0.1
2-Methyl (S and R mixture)-19-Nor-20S-1,25-(OH) ₂ D ₃	6.7 \pm 0.6	8.1 \pm 0.3

Male Holtzman strain weanling rats were obtained from the Sprague Dawley Co. (Indianapolis, IN) and fed the 0.47% calcium, 0.3% phosphorus diet described by Suda et al. (J. Nutr. 100, 1049-1052, 1970) for 1 week and then fed the same diet containing 0.02% calcium and 0.3% phosphorus for 2 additional weeks. At this point, they received a single

intrajugular injection of the indicated dose dissolved in 0.1 ml of 95% propylene glycol/5% ethanol. Twenty-four hours later they were sacrificed and intestinal calcium transport and serum calcium were determined as described in Table 1. The dose of the compounds was 650
5 pmol and there were 5 animals per group. The data are expressed as mean \pm SEM.

For treatment purposes, the novel compounds of this invention defined by formula I may be formulated for pharmaceutical applications as a solution in innocuous solvents, or as an emulsion, suspension or
10 dispersion in suitable solvents or carriers, or as pills, tablets or capsules, together with solid carriers, according to conventional methods known in the art. Any such formulations may also contain other pharmaceutically-acceptable and non-toxic excipients such as stabilizers, anti-oxidants, binders, coloring agents or emulsifying or taste-modifying agents.

15 The compounds may be administered orally, topically, parenterally or transdermally. The compounds are advantageously administered by injection or by intravenous infusion or suitable sterile solutions, or in the form of liquid or solid doses via the alimentary canal, or in the form of creams, ointments, patches, or similar vehicles suitable for transdermal
20 applications. Doses of from 0.1 μ g to 50 μ g per day of the compounds are appropriate for treatment purposes, such doses being adjusted according to the disease to be treated, its severity and the response of the subject as is well understood in the art. Since the new compounds exhibit specificity of action, each may be suitably administered alone, or together
25 with graded doses of another active vitamin D compound -- e.g. 1 α -hydroxyvitamin D₂ or D₃, or 1 α ,25-dihydroxyvitamin D₃ -- in situations where different degrees of bone mineral mobilization and calcium transport stimulation is found to be advantageous.

Compositions for use in the above-mentioned treatment of psoriasis and other malignancies comprise an effective amount of one or more 2-substituted-19-nor-vitamin D compound as defined by the above formula I as the active ingredient, and a suitable carrier. An effective
5 amount of such compounds for use in accordance with this invention is from about 0.01 μ g to about 100 μ g per gm of composition, and may be administered topically, transdermally, orally or parenterally in dosages of from about 0.1 μ g/day to about 100 μ g/day.

The compounds may be formulated as creams, lotions, ointments,
10 topical patches, pills, capsules or tablets, or in liquid form as solutions, emulsions, dispersions, or suspensions in pharmaceutically innocuous and acceptable solvent or oils, and such preparations may contain in addition other pharmaceutically innocuous or beneficial components, such as stabilizers, antioxidants, emulsifiers, coloring agents, binders or taste-
15 modifying agents.

The compounds are advantageously administered in amounts sufficient to effect the differentiation of promyelocytes to normal macrophages. Dosages as described above are suitable, it being understood that the amounts given are to be adjusted in accordance with the severity
20 of the disease, and the condition and response of the subject as is well understood in the art.

The formulations of the present invention comprise an active ingredient in association with a pharmaceutically acceptable carrier therefore and optionally other therapeutic ingredients. The carrier must
25 be "acceptable" in the sense of being compatible with the other ingredients of the formulations and not deleterious to the recipient thereof.

Formulations of the present invention suitable for oral administration may be in the form of discrete units as capsules, sachets,
30 tablets or lozenges, each containing a predetermined amount of the active

ingredient; in the form of a powder or granules; in the form of a solution or a suspension in an aqueous liquid or non-aqueous liquid; or in the form of an oil-in-water emulsion or a water-in-oil emulsion.

Formulations for rectal administration may be in the form of a
5 suppository incorporating the active ingredient and carrier such as cocoa butter, or in the form of an enema.

Formulations suitable for parenteral administration conveniently comprise a sterile oily or aqueous preparation of the active ingredient which is preferably isotonic with the blood of the recipient.

10 Formulations suitable for topical administration include liquid or semi-liquid preparations such as liniments, lotions, applicants, oil-in-water or water-in-oil emulsions such as creams, ointments or pastes; or solutions or suspensions such as drops; or as sprays.

For asthma treatment, inhalation of powder, self-propelling or
15 spray formulations, dispensed with a spray can, a nebulizer or an atomizer can be used. The formulations, when dispensed, preferably have a particle size in the range of 10 to 100 μ .

The formulations may conveniently be presented in dosage unit form and may be prepared by any of the methods well known in the art of
20 pharmacy. By the term "dosage unit" is meant a unitary, i.e. a single dose which is capable of being administered to a patient as a physically and chemically stable unit dose comprising either the active ingredient as such or a mixture of it with solid or liquid pharmaceutical diluents or carriers.

25 In its broadest application, the present invention relates to any 19-nor-2-alkyl analogs of vitamin D which have the vitamin D nucleus. By vitamin D nucleus, it is meant a central part consisting of a substituted chain of five carbon atoms which correspond to positions 8, 14, 13, 17 and 20 of vitamin D, and at the ends of which are connected at position 20 a
30 structural moiety representing any of the typical side chains known for

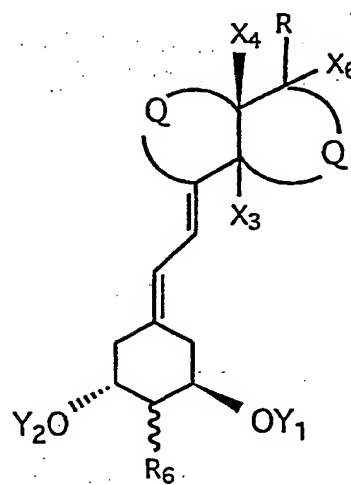
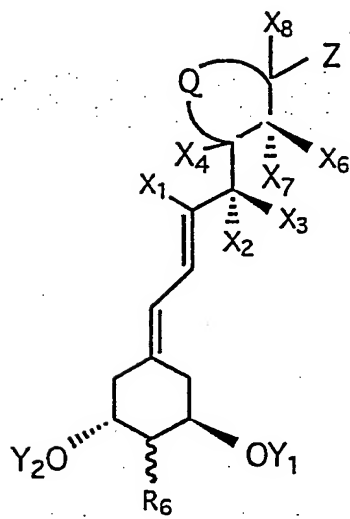
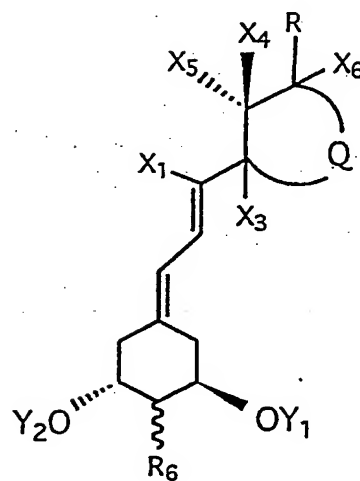
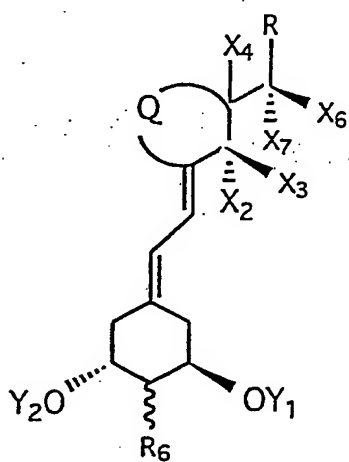
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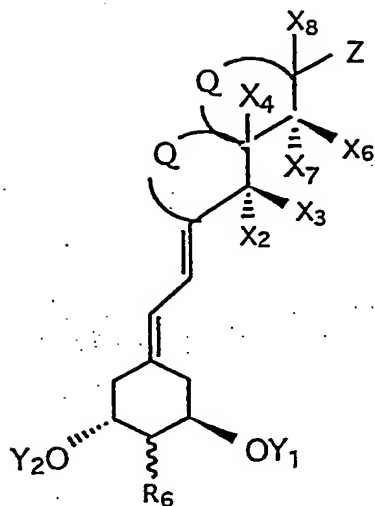
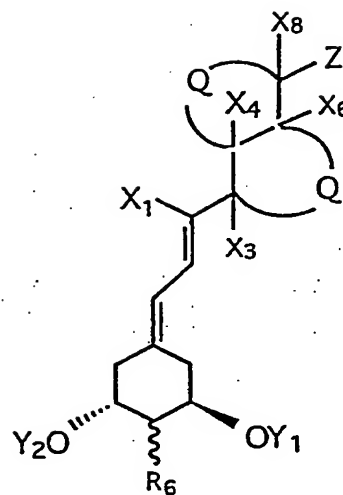
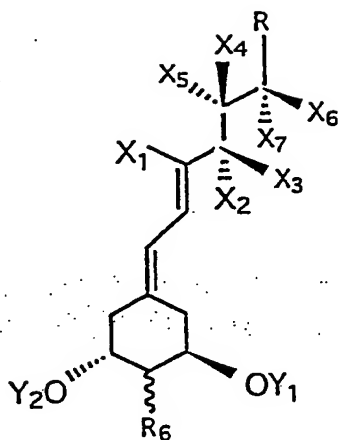
with those of formula I, also encompassed by the present invention:



20

Preferred compounds of the present invention may be represented by one of the following formulae:



**If****Ig****Ih**

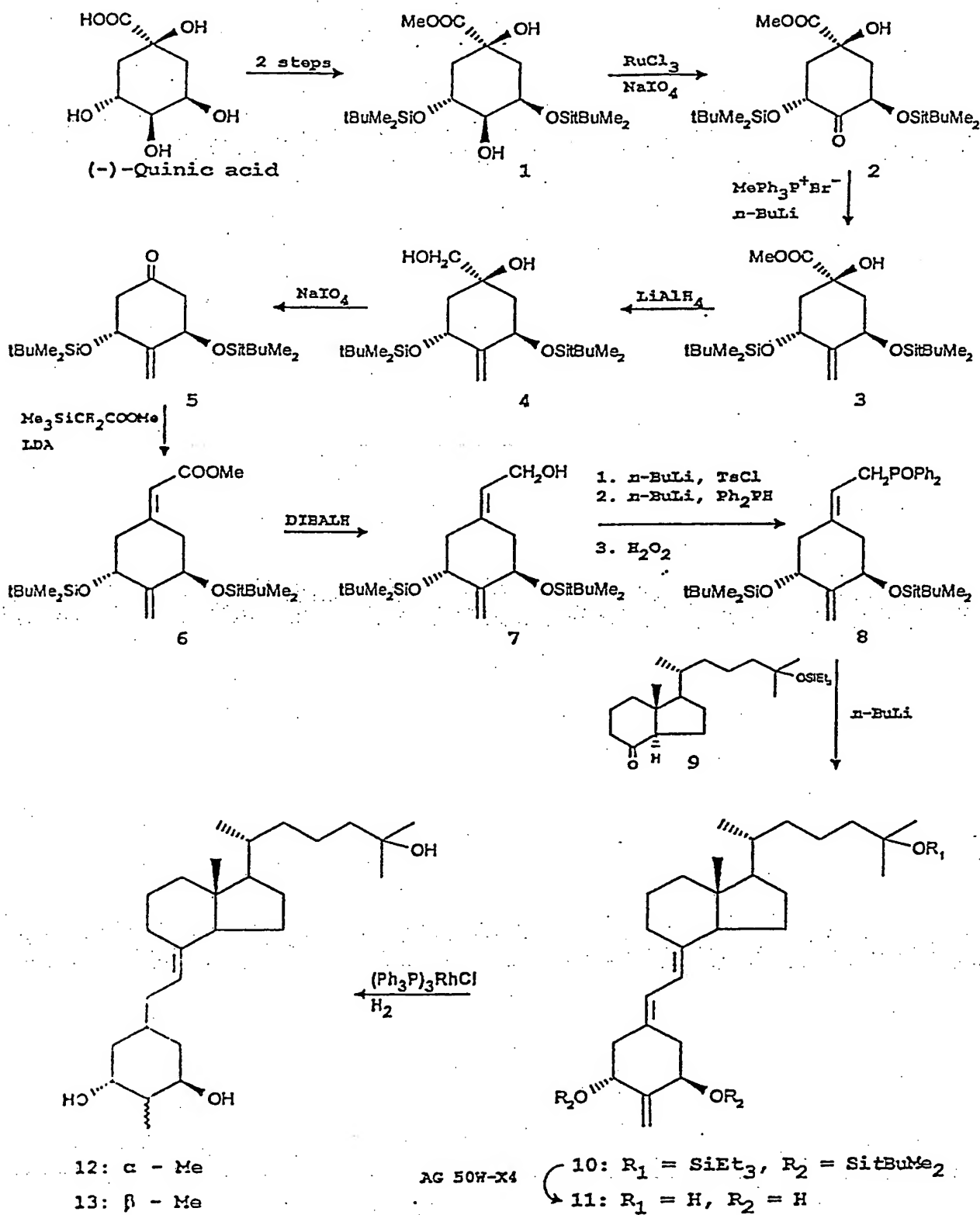
In the above formulae Ib, Ic, Id, Ie, If, Ig and Ih, the definitions of Y₁, Y₂, R₆, R, Z, X₁, X₂, X₃, X₄, X₅, X₆, X₇ and X₈ are as previously set forth herein. The substituent Q represents a saturated or unsaturated, substituted or unsubstituted, hydrocarbon chain comprised of 0, 1, 2, 3 or 4 carbon atoms, but is preferably the group -(CH₂)_k- where k is an integer equal to 2 or 3.

Methods for making compounds of formulae Ia-Ih are known.

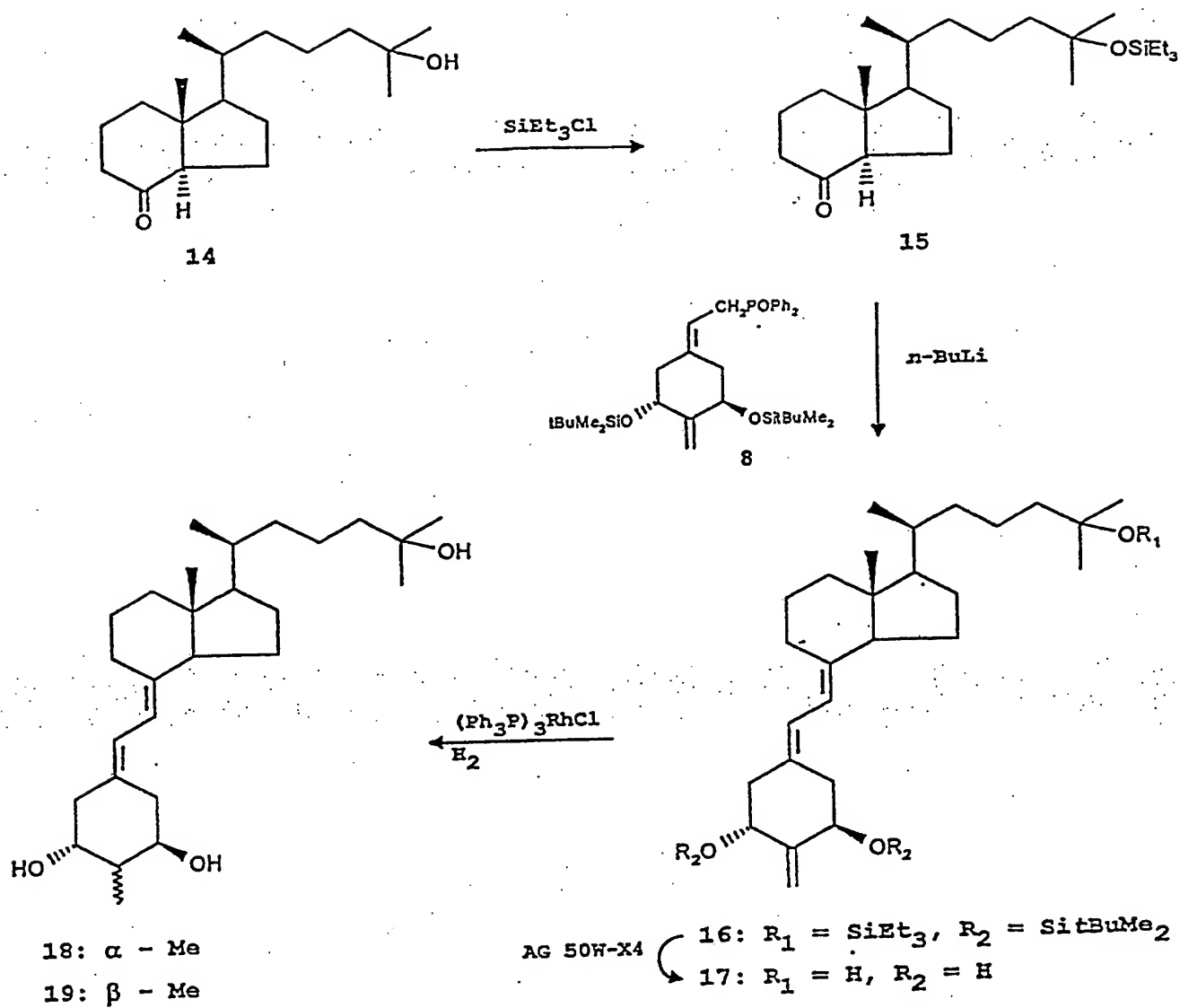
Specifically, reference is made to International Application Number PCT/EP94/02294 filed 7 July 1994 and published 19 January 1995 under

International Publication Number WO95/01960.

SCHEME I

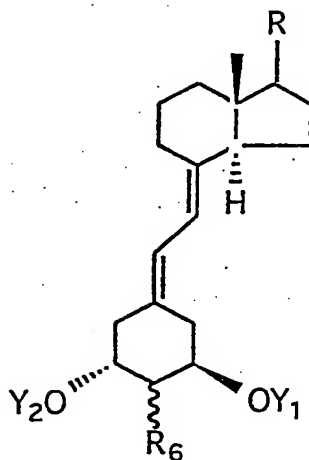


SCHEME II



We claim:

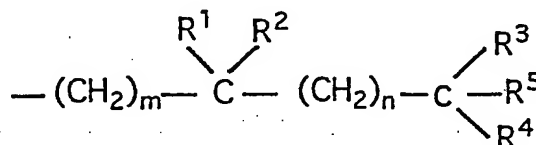
1. A compound having the formula:



where Y_1 and Y_2 , which may be the same or different, are each selected from the group consisting of hydrogen and a hydroxy-protecting group, R_6 is selected from alkyl, hydroxyalkyl and fluoroalkyl, and where the group R is represented by the structure:



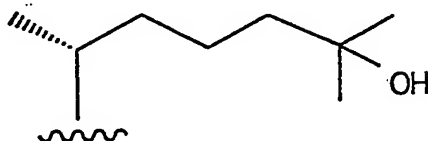
where the stereochemical center at carbon 20 may have the R or S configuration, and where Z is selected from Y, -OY, -CH₂OY, -C≡CY and -CH=CHY, where the double bond may have the cis or trans geometry, and where Y is selected from hydrogen, methyl, -COR⁵ and a radical of the structure:



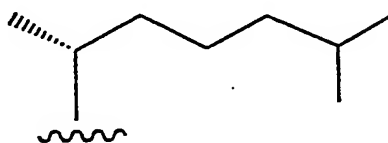
where m and n, independently, represent the integers from 0 to 5, where R^1 is selected from hydrogen, deuterium, hydroxy, protected hydroxy,

fluoro, trifluoromethyl, and C₁₋₅-alkyl, which may be straight chain or branched and, optionally, bear a hydroxy or protected-hydroxy substituent, and where each of R², R³, and R⁴, independently, is selected from deuterium, deuterioalkyl, hydrogen, fluoro, trifluoromethyl and C₁₋₅ alkyl, which may be straight-chain or branched, and optionally, bear a hydroxy or protected-hydroxy substituent, and where R¹ and R², taken together, represent an oxo group, or an alkylidene group, =CR²R³, or the group -(CH₂)_p-, where p is an integer from 2 to 5, and where R³ and R⁴, taken together, represent an oxo group, or the group -(CH₂)_q-, where q is an integer from 2 to 5, and where R⁵ represents hydrogen, hydroxy, protected hydroxy, or C₁₋₅ alkyl and wherein any of the CH-groups at positions 20, 22, or 23 in the side chain may be replaced by a nitrogen atom, or where any of the groups -CH(CH₃)-, -CH(R³)-, or -CH(R²)- at positions 20, 22, and 23, respectively, may be replaced by an oxygen or sulfur atom.

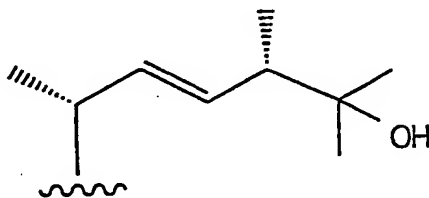
2. The compound of claim 1 where R is a side chain of the formula



3. The compound of claim 1 where R is a side chain of the formula

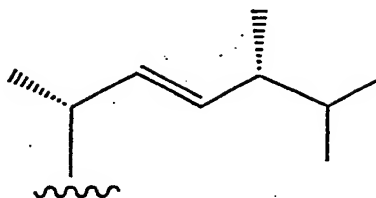


4. The compound of claim 1 where R is a side chain of the formula



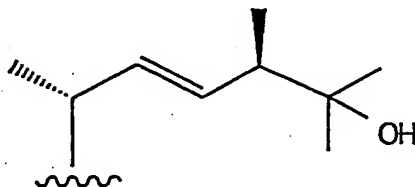
5. The compound of claim 1 where R is a side chain of the formula

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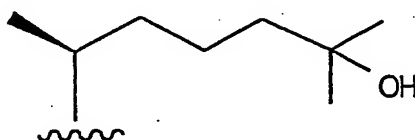


6. The compound of claim 1 where R is a side chain of the formula

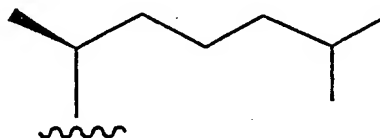
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7. The compound of claim 1 where R is a side chain of the formula

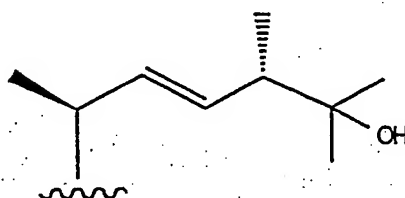


8. The compound of claim 1 where R is a side chain of the formula



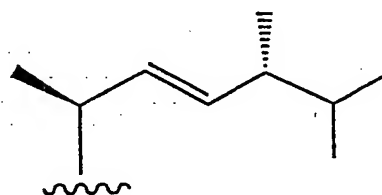
9. The compound of claim 1 where R is a side chain of the formula

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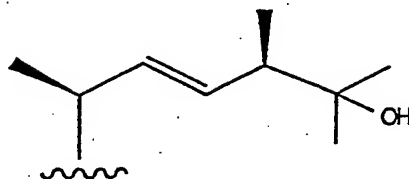


10. The compound of claim 1 where R is a side chain of the formula

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11. The compound of claim 1 where R is a side chain of the formula

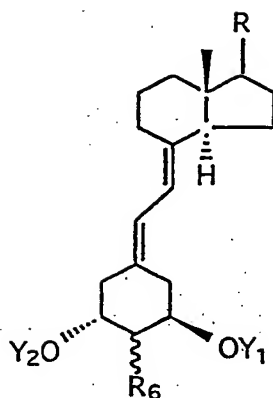


5.

12. 2(S)-methyl-19-nor-1 α ,25-dihydroxyvitamin D₃.
13. 2(R)-methyl-19-nor-1 α ,25-dihydroxyvitamin D₃.
14. 2(S)-methyl-19-nor-20(S)-1 α ,25-dihydroxyvitamin D₃.
15. 2(R)-methyl-19-nor-20(S)-1 α ,25-dihydroxyvitamin D₃.
16. A pharmaceutical composition containing at least one compound as claimed in claim 1 together with a pharmaceutically acceptable excipient.
17. The pharmaceutical composition of claim 16 containing 2(S)-methyl-19-nor-1 α ,25-dihydroxyvitamin D₃ in an amount from about 0.1 μ g to about 50 μ g.
18. The pharmaceutical composition of claim 16 containing 2(R)-methyl-19-nor-1 α ,25-dihydroxyvitamin D₃ in an amount from about 0.1 μ g to about 50 μ g.
19. The pharmaceutical composition of claim 16 containing 2(S)-methyl-19-nor-20(S)-1 α ,25-dihydroxyvitamin D₃ in an amount from about 0.1 μ g to about 50 μ g.
20. The pharmaceutical composition of claim 16 containing 2(R)-methyl-19-nor-20(S)-1 α ,25-dihydroxyvitamin D₃ in an amount from about 0.1 μ g to about 50 μ g.
21. A method of treating metabolic bone disease where it is desired to maintain or increase bone mass comprising administering to a patient with said disease an effective amount of a compound having the formula:

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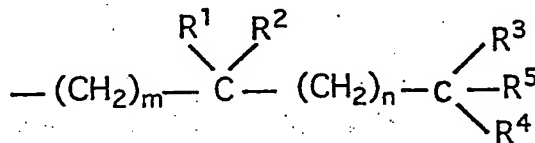


where Y_1 and Y_2 , which may be the same or different, are each selected from the group consisting of hydrogen and a hydroxy-protecting group, R_6 is selected from alkyl, hydroxyalkyl and fluoroalkyl, and where the group R is represented by the structure:



where the stereochemical center at carbon 20 may have the R or S configuration, and where Z is selected from Y, -OY, -CH₂OY, -C≡CY and -CH=CHY, where the double bond may have the cis or trans geometry, and where Y is selected from hydrogen, methyl, -COR⁵ and a radical of the structure:

25



where m and n, independently, represent the integers from 0 to 5, where R_1 is selected from hydrogen, deuterium, hydroxy, protected hydroxy, fluoro, trifluoromethyl, and C₁₋₅-alkyl, which may be straight chain or branched and, optionally, bear a hydroxy or protected-hydroxy substituent, and where each of R_2 , R_3 , and R_4 , independently, is selected from deuterium, deuterioalkyl, hydrogen, fluoro, trifluoromethyl and C₁₋₅ alkyl,

35. which may be straight-chain or branched, and optionally, bear a hydroxy or protected-hydroxy substituent, and where R¹ and R², taken together, represent an oxo group, or an alkylidene group, =CR²R³, or the group -(CH₂)_p-, where p is an integer from 2 to 5, and where R³ and R⁴, taken together, represent an oxo group, or the group
- 40 -(CH₂)_q-, where q is an integer from 2 to 5, and where R⁵ represents hydrogen, hydroxy, protected hydroxy, or C₁₋₅ alkyl and wherein any of the CH-groups at positions 20, 22, or 23 in the side chain may be replaced by a nitrogen atom, or where any of the groups -CH(CH₃)-, -CH(R³)-, or -CH(R²)- at positions 20, 22, and 23, respectively, may be replaced by an oxygen or
- 45 sulfur atom.

22. The method of claim 21 where the disease is senile osteoporosis.

23. The method of claim 21 where the disease is postmenopausal osteoporosis.

24. The method of claim 21 where the disease is steroid-induced osteoporosis.

25. The method of claim 21 where the disease is low bone turnover osteoporosis.

26. The method of claim 21 where the disease is osteomalacia.

27. The method of claim 21 where the disease is renal osteodystrophy.

28. The method of claim 21 wherein the compound is administered orally.

29. The method of claim 21 wherein the compound is administered parenterally.

30. The method of claim 21 wherein the compound is administered transdermally.

31. The method of claim 21 wherein the compound is administered in a dosage of from 0.1µg to 50µg per day.

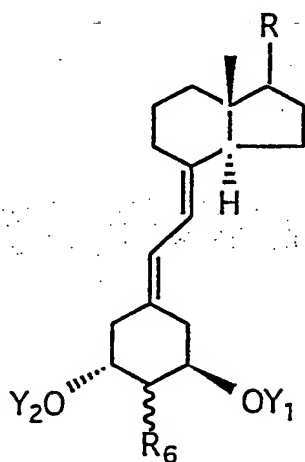
32. The method of claim 21 wherein the compound is 2(S)-methyl-19-nor-1 α ,25-dihydroxyvitamin D₃.

33. The method of claim 21 wherein the compound is 2(R)-methyl-19-nor-1 α ,25-dihydroxyvitamin D₃.

34. The method of claim 21 wherein the compound is 2(S)-methyl-19-nor-20(S)-1 α ,25-dihydroxyvitamin D₃.

35. The method of claim 21 wherein the compound is 2(R)-methyl-19-nor-20(S)-1 α ,25-dihydroxyvitamin D₃.

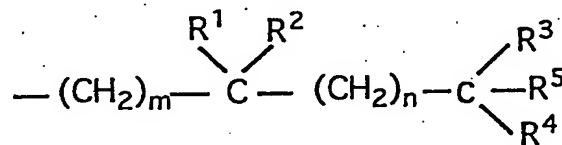
36. A method of treating psoriasis comprising administering to a patient with said disease an effective amount of a compound having the formula:



where Y₁ and Y₂, which may be the same or different, are each selected from the group consisting of hydrogen and a hydroxy-protecting group, R₆ is selected from alkyl, hydroxyalkyl and fluoroalkyl, and where the group R is represented by the structure:



where the stereochemical center at carbon 20 may have the R or S configuration, and where Z is selected from Y, -OY, -CH₂OY, -C≡CY and -CH=CHY, where the double bond may have the cis or trans geometry, and
 25 where Y is selected from hydrogen, methyl, -COR⁵ and a radical of the structure:



30 where m and n, independently, represent the integers from 0 to 5, where R¹ is selected from hydrogen, deuterium, hydroxy, protected hydroxy, fluoro, trifluoromethyl, and C₁₋₅-alkyl, which may be straight chain or branched and, optionally, bear a hydroxy or protected-hydroxy substituent, and where each of R², R³, and R⁴, independently, is selected from
 35 deuterium, deuterioalkyl, hydrogen, fluoro, trifluoromethyl and C₁₋₅ alkyl, which may be straight-chain or branched, and optionally, bear a hydroxy or protected-hydroxy substituent, and where R¹ and R², taken together, represent an oxo group, or an alkylidene group, =CR²R³, or the group -(CH₂)_p-, where p is an integer from 2 to 5, and where R³ and R⁴, taken
 40 together, represent an oxo group, or the group -(CH₂)_q-, where q is an integer from 2 to 5, and where R⁵ represents hydrogen, hydroxy, protected hydroxy, or C₁₋₅ alkyl and wherein any of the CH-groups at positions 20, 22, or 23 in the side chain may be replaced by a nitrogen atom, or where any of the groups -CH(CH₃)-, -CH(R³)-, or -CH(R²)- at positions 20, 22, and
 45 23, respectively, may be replaced by an oxygen or sulfur atom.

37. The method of claim 36 wherein the compound is 2(S)-methyl-19-nor-1 α ,25-dihydroxyvitamin D₃.

38. The method of claim 36 wherein the compound is 2(R)-methyl-19-nor-1 α ,25-dihydroxyvitamin D₃.

39. The method of claim 36 wherein the compound is 2(S)-methyl-19-nor-20(S)-1 α ,25-dihydroxyvitamin D₃.

40. The method of claim 36 wherein the compound is 2(R)-methyl-19-nor-20(S)-1 α ,25-dihydroxyvitamin D₃.

41. The method of claim 36 wherein said effective amount comprises about 0.01 μ g/day to about 100 μ g/day of said compound.

Competitive Binding to PINE-VDR

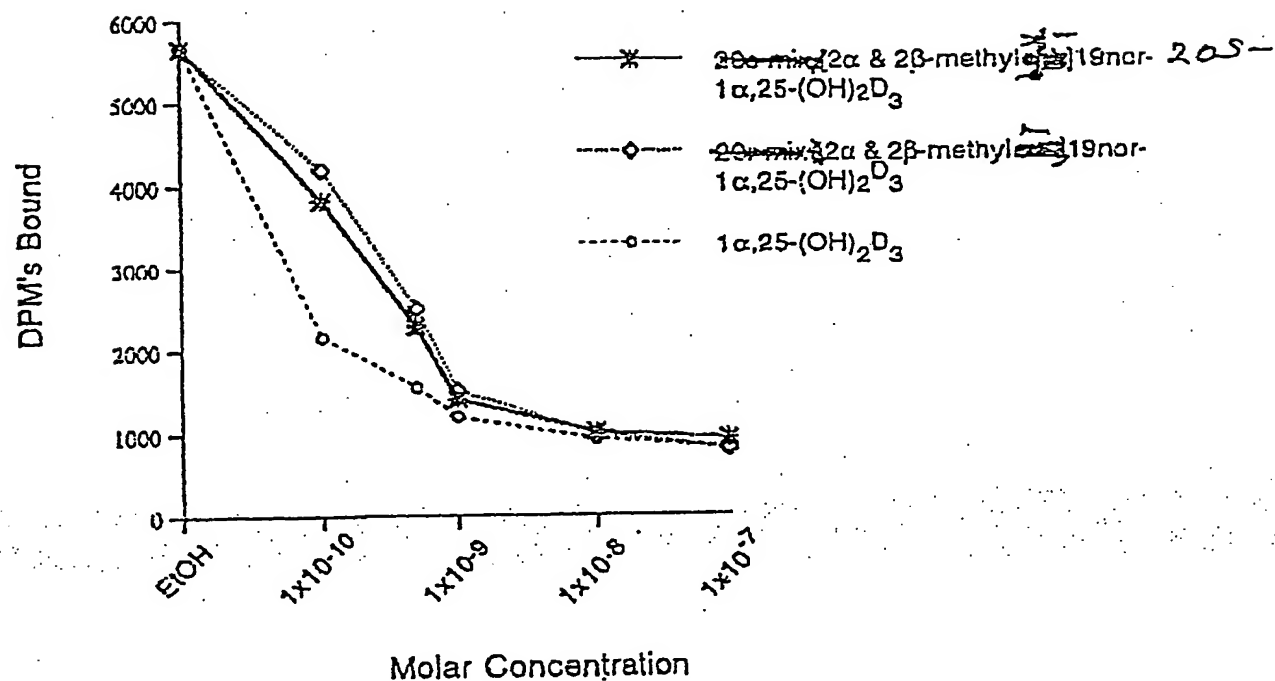


FIGURE 1

HL-60 Cell Differentiation - NBT

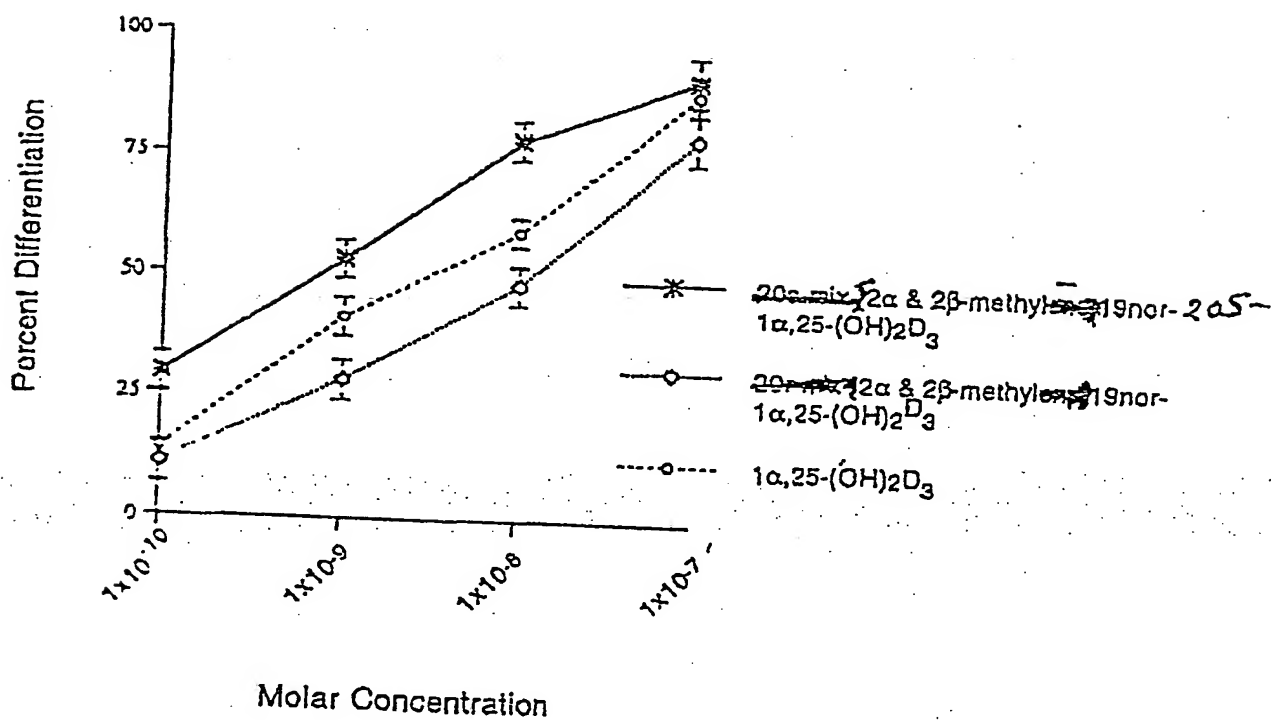


FIGURE 2

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 98/02975

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 C07C401/00 A61K31/59

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 C07C A61K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 536 713 A (H.F. DELUCA ET AL) 16 July 1996 cited in the application see column 17, line 38 - column 19, line 42; schemes I, IV; claims	1-3, 16, 23, 25, 28-31, 36, 41
A	--- CHEMICAL ABSTRACTS, vol. 121, no. 21, 21 November 1994 Columbus, Ohio, US; abstract no. 256121m, XP002066055 see abstract; RN 158388-02-4, 158387-98-5, 158388-05-7, 158388-07-9, 158388-09-1, 158388-11-5, 158388-13-7, 158388-15-9, 158388-21-7, 158388-23-9, 158388-25-1 & JP 06 041 059 A (CHUGAI PHARMACEUTICAL CO LTD) 15 February 1994 --- -/--	1-3, 16, 21

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

*** Special categories of cited documents:**

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

X document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

Y document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

Z document member of the same patent family

Date of the actual completion of the international search

28 May 1998

Date of mailing of the international search report

06. 08. 1998

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Fax: (+31-70) 340-3016

Authorized officer

Van Amsterdam, L

INTERNATIONAL SEARCH REPORT

Intern. Application No
PCT/US 98/02975

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 666 634 A (K. MIYAMOTO ET AL) 19 May 1987 cited in the application see column 1, lines 6-13; claims ---	1-3,16, 21,26
A	WO 96 01811 A (THE JOHN-HOPKINS UNIVERSITY) 25 January 1996 see pages 3-4; page 20, line 1 - page 21, line 6; claims 1-6 -----	1,2,16, 21,23

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 98/02975

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☒ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
Although claims 21-41 are directed to a method of treatment of the human/animal body, the search has been carried out and based on the alleged effects of the compound/composition.
2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 98/02975

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5536713 A	16-07-1996	DE 69400495 D	17-10-1996
		DE 69400495 T	30-04-1997
		EP 0619306 A	12-10-1994
		JP 6321894 A	22-11-1994
US 4666634 A	19-05-1987	CA 1330806 A	19-07-1994
		CN 85108857 A,B	09-07-1986
		DK 561485 A,B,	06-06-1986
		EP 0184206 A	11-06-1986
		JP 1894284 C	26-12-1994
		JP 6023185 B	30-03-1994
		JP 61267549 A	27-11-1986
		KR 9402981 B	09-04-1994
WO 9601811 A	25-01-1996	NONE	

Form PCT/ISA/210 (patent family annex) (July 1992)

treat psoriasis in an amount from about 0.01 μ g/gm to about 100 μ g/gm of the composition, and may be administered topically, transdermally, orally or parenterally in dosages of from about 0.01 μ g/day to about 100 μ g/day.

5 This invention also provides novel intermediate compounds formed during the synthesis of the end products.

This invention also provides a novel synthesis for the production of the end products of structure I.

10

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a graph illustrating the relative activity of a mixture of 2 α and 2 β -methyl-19-nor-20S-1 α ,25-dihydroxyvitamin D₃, a mixture of 2 α and 2 β -methyl-19-nor-1 α ,25-dihydroxyvitamin D₃ and 1 α ,25-dihydroxyvitamin D₃ to compete for binding of [3H]-1,25-(OH)₂-D₃ to the vitamin D pig intestinal nuclear receptor; and

15

Figure 2 is a graph illustrating the percent HL-60 cell differentiation as a function of the concentration of a mixture of 2 α and 2 β -methyl-19-nor-20S-1 α ,25-dihydroxyvitamin D₃, a mixture of 2 α and 2 β -methyl-19-nor-1 α ,25-dihydroxyvitamin D₃ and 1 α ,25-dihydroxyvitamin D₃.

20

DETAILED DESCRIPTION OF THE INVENTION

As used in the description and in the claims, the term "hydroxy-protecting group" signifies any group commonly used for the temporary protection of hydroxy functions, such as for example, alkoxycarbonyl, acyl, alkylsilyl or alkylarylsilyl groups (hereinafter referred to simply as "silyl" groups), and alkoxyalkyl groups. Alkoxycarbonyl protecting

25

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groups are alkyl-O-CO- groupings such as methoxycarbonyl, ethoxycarbonyl, propoxycarbonyl, isopropoxycarbonyl, butoxycarbonyl, isobutoxycarbonyl, tert-butoxycarbonyl, benzyloxycarbonyl or allyloxycarbonyl. The term "acyl" signifies an alkanoyl group of 1 to 6
5 carbons, in all of its isomeric forms, or a carboxyalkanoyl group of 1 to 6 carbons, such as an oxalyl, malonyl, succinyl, glutaryl group, or an aromatic acyl group such as benzoyl, or a halo, nitro or alkyl substituted benzoyl group. The word "alkyl" as used in the description or the claims, denotes a straight-chain or branched alkyl radical of 1 to
10 10 carbons, in all its isomeric forms. Alkoxyalkyl protecting groups are groupings such as methoxymethyl, ethoxymethyl, methoxyethoxymethyl, or tetrahydrofuranyl and tetrahydropyranyl. Preferred silyl-protecting groups are trimethylsilyl, triethylsilyl, t-butyl dimethylsilyl, dibutylmethylsilyl, diphenylmethylsilyl,
15 phenyldimethylsilyl, diphenyl-t-butylsilyl and analogous alkylated silyl radicals. The term "aryl" specifies a phenyl-, or an alkyl-, nitro- or halo-substituted phenyl group.

A "protected hydroxy" group is a hydroxy group derivatised or protected by any of the above groups commonly used for the temporary
20 or permanent protection of hydroxy functions, e.g. the silyl, alkoxyalkyl, acyl or alkoxycarbonyl groups, as previously defined. The terms "hydroxyalkyl", "deuteroalkyl" and "fluoroalkyl" refer to an alkyl radical substituted by one or more hydroxy, deuterium or fluoro groups respectively.

25 It should be noted in this description that the term "24-homo" refers to the addition of one methylene group and the term "24-dihomo" refers to the addition of two methylene groups at the carbon 24 position in the side chain. Likewise, the term "trihomo" refers to the

- 10 -

addition of three methylene groups. Also, the term "26,27-dimethyl" refers to the addition of a methyl group at the carbon 26 and 27 positions so that for example R³ and R⁴ are ethyl groups. Likewise, the term "26,27-diethyl" refers to the addition of an ethyl group at the 26 and 27 positions so that R³ and R⁴ are propyl groups.

In the following lists of compounds, the particular substituent attached at the carbon 2 position should be added to the nomenclature. For example, if a methyl group is the alkyl substituent, the term "2-methyl" should precede each of the named compounds. If an ethyl group is the alkyl substituent, the term "2-ethyl" should precede each of the named compounds, and so on. In addition, if the methyl group attached at the carbon 20 position is in its epi or unnatural configuration, the term "20(S)" or "20-epi" should be included in each of the following named compounds. The named compounds could also be of the vitamin D₂ type if desired.

Specific and preferred examples of the 2-alkyl-compounds of structure I when the side chain is unsaturated are:

19-nor-24-homo-1,25-dihydroxy-22-dehydrovitamin D₃;

19-nor-24-dihomo-1,25-dihydroxy-22-dehydrovitamin D₃;

20 19-nor-24-trihomo-1,25-dihydroxy-22-dehydrovitamin D₃;

19-nor-26,27-dimethyl-24-homo-1,25-dihydroxy-22-dehydrovitamin D₃;

19-nor-26,27-dimethyl-24-dihomo-1,25-dihydroxy-22-dehydrovitamin D₃;

25 19-nor-26,27-dimethyl-24-trihomo-1,25-dihydroxy-22-dehydrovitamin D₃;

19-nor-26,27-diethyl-24-homo-1,25-dihydroxy-22-dehydrovitamin D₃;

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19-nor-26,27-diethyl-24-dihomo-1,25-dihydroxy-22-dehydrovitamin D₃;

19-nor-26,27-diethyl-24-trihomo-1,25-dihydroxy-22-dehydrovitamin D₃;

5 19-nor-26,27-dipropoyl-24-homo-1,25-dihydroxy-22-dehydrovitamin D₃;

19-nor-26,27-dipropyl-24-dihomo-1,25-dihydroxy-22-dehydrovitamin D₃; and

10 19-nor-26,27-dipropyl-24-trihomo-1,25-dihydroxy-22-dehydrovitamin D₃.

Specific and preferred examples of the 2-alkyl-compounds of structure I when the side chain is saturated are:

19-nor-24-homo-1,25-dihydroxyvitamin D₃;

19-nor-24-dihomo-1,25-dihydroxyvitamin D₃;

15 19-nor-24-trihomo-1,25-dihydroxyvitamin D₃;

19-nor-26,27-dimethyl-24-homo-1,25-dihydroxyvitamin D₃;

19-nor-26,27-dimethyl-24-dihomo-1,25-dihydroxyvitamin D₃;

19-nor-26,27-dimethyl-24-trihomo-1,25-dihydroxyvitamin D₃;

19-nor-26,27-diethyl-24-homo-1,25-dihydroxyvitamin D₃;

20 19-nor-26,27-diethyl-24-dihomo-1,25-dihydroxyvitamin D₃;

19-nor-26,27-diethyl-24-trihomo-1,25-dihydroxyvitamin D₃;

19-nor-26,27-dipropyl-24-homo-1,25-dihydroxyvitamin D₃;

19-nor-26,27-dipropyl-24-dihomo-1,25-dihydroxyvitamin D₃;

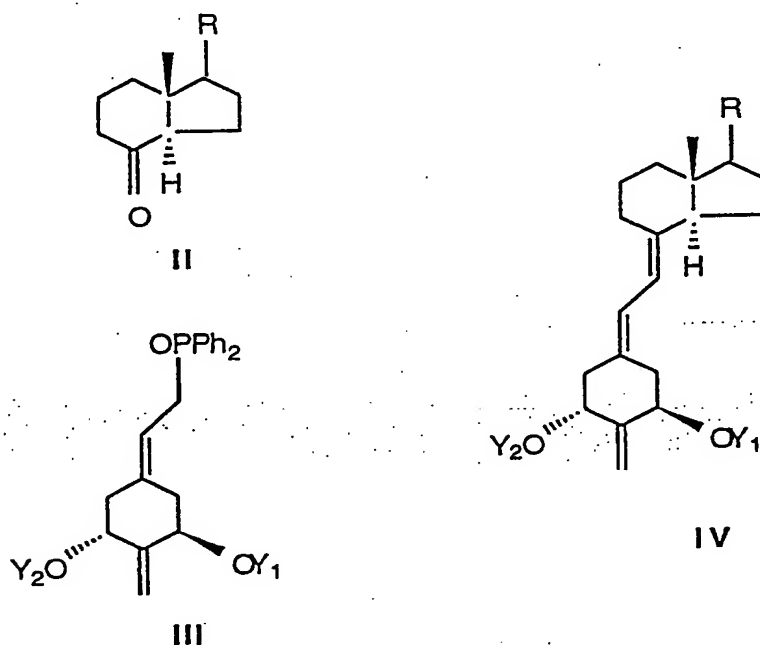
and

25 19-nor-26,27-dipropyl-24-trihomo-1,25-dihydroxyvitamin D₃.

The preparation of 1 α -hydroxy-2-alkyl-19-nor-vitamin D compounds, particularly 1 α -hydroxy-2-methyl-19-nor-vitamin D

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compounds, having the basic structure I can be accomplished by a common general method, i.e. the condensation of a bicyclic Windaus-Grundmann type ketone II with the allylic phosphine oxide III to the corresponding 2-methylene-19-nor-vitamin D analogs IV followed by a selective reduction of the exomethylene group at C-2 in the latter compounds:



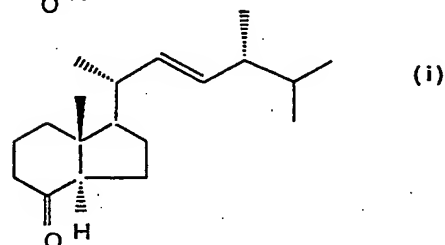
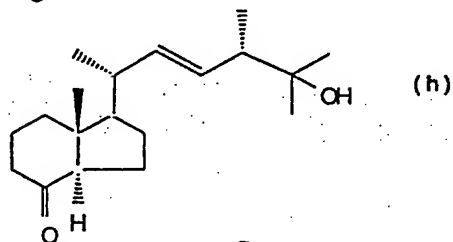
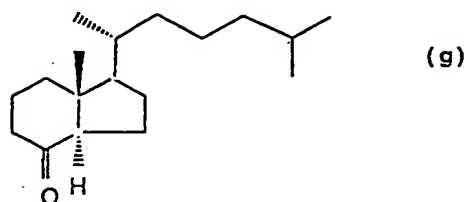
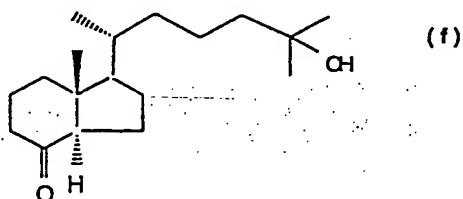
In the structures II, III, and IV groups Y_1 and Y_2 and R represent groups defined above; Y_1 and Y_2 are preferably hydroxy-protecting groups, it being also understood that any functionalities in R that might be sensitive, or that interfere with the condensation reaction, be suitable protected as is well-known in the art. The process shown above represents an application of the convergent synthesis concept, which has been applied effectively for the preparation of vitamin D compounds [e.g. Lythgoe et al., J. Chem. Soc. Perkin Trans. I, 590 (1978); Lythgoe, Chem. Soc. Rev. 9, 449 (1983); Toh et al., J. Org. Chem. 48, 1414 (1983); Baggolini et al., J. Org. Chem. 51, 3098 (1986); Sardina et al., J. Org.

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Chem. 51, 1264 (1986); J. Org. Chem. 51, 1269 (1986); DeLuca et al., U.S. Pat. No. 5,086,191; DeLuca et al., U.S. Pat. No. 5,536,713].

Hydrindanones of the general structure II are known, or can be prepared by known methods. Specific important examples of such known bicyclic ketones are the structures with the side chains (a), (b), (c) and (d) described above, i.e. 25-hydroxy Grundmann's ketone (f) [Baggiolini et al., J. Org. Chem, 51, 3098 (1986)]; Grundmann's ketone (g) [Inhoffen et al., Chem. Ber. 90, 664 (1957)]; 25-hydroxy Windaus ketone (h) [Baggiolini et al., J. Org. Chem., 51, 3098 (1986)] and Windaus ketone (i) [Windaus et al., Ann., 524, 297 (1936)]:



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For the preparation of the required phosphine oxides of general structure III, a new synthetic route has been developed starting from methyl quinate derivative 1, easily obtained from commercial (1R,3R,4S,5R)-(-)-quinic acid as described by Perlman et al.,

- 5 Tetrahedron Lett. 32, 7663 (1991) and DeLuca et al., U.S. Pat. No. 5,086,191. The overall process of transformation of the starting methyl ester 1 into the desired A-ring synthons, is summarized by the SCHEME I. Thus, the secondary 4-hydroxyl group of 1 was oxidized with RuO₄ (a catalytic method with RuCl₃ and NaIO₄ as co-oxidant). Use of
10 such a strong oxidant was necessary for an effective oxidation process of this very hindered hydroxyl. However, other more commonly used oxidants can also be applied (e.g. pyridinium dichromate), although the reactions usually require much longer time for completion. Second step of the synthesis comprises the Wittig reaction of the sterically
15 hindered 4-keto compound 2 with ylide prepared from methyltriphenylphosphonium bromide and *n*-butyllithium. Other bases can be also used for the generation of the reactive methylenephosphorane, like *t*-BuOK, NaNH₂, NaH, K/HMPT, NaN(TMS)₂, etc. For the preparation of the 4-methylene compound 3 some described
20 modifications of the Wittig process can be used, e.g. reaction of 2 with activated methylenetriphenyl-phosphorane [Corey et al., Tetrahedron Lett. 26, 555 (1985)]. Alternatively, other methods widely used for methylenation of unreactive ketones can be applied, e.g. Wittig-Horner reaction with the PO-ylid obtained from methyldiphenylphosphine oxide
25 upon deprotonation with *n*-butyllithium [Schosse et al., Chimia 30, 197 (1976)], or reaction of ketone with sodium methylsulfinate [Corey et al., J. Org. Chem. 28, 1128 (1963)] and potassium methylsulfinate [Greene et al., Tetrahedron Lett. 3755 (1976)]. Reduction of the ester 3

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with lithium aluminum hydride or other suitable reducing agent (e.g. DIBALH) provided the diol 4 which was subsequently oxidized by sodium periodate to the cyclohexanone derivative 5. The next step of the process comprises the Peterson reaction of the ketone 5 with methyl(trimethylsilyl)acetate. The resulting allylic ester 6 was treated with diisobutylaluminum hydride and the formed allylic alcohol 7 was in turn transformed to the desired A-ring phosphine oxide 8. Conversion of 7 to 8 involved 3 steps, namely, *in situ* tosylation with *n*-butyllithium and *p*-toluenesulfonyl chloride, followed by reaction with diphenylphosphine lithium salt and oxidation with hydrogen peroxide.

Several 2-methylene-19-nor-vitamin D compounds of the general structure IV may be synthesized using the A-ring synthon 8 and the appropriate Windaus-Grundmann ketone II having the desired side chain structure. Thus, for example, Wittig-Horner coupling of the lithium phosphinoxy carbanion generated from 8 and *n*-butyllithium with the protected 25-hydroxy Grundmann's ketone 9 prepared according to published procedure [Sicinski et al., J. Med. Chem. 37, 3730 (1994)] gave the expected protected vitamin compound 10. This, after deprotection with AG 50W-X4 cation exchange resin afforded 1 α ,25-dihydroxy-2-methylene-19-nor-vitamin D₃ (11).

The final step of the process was the selective homogeneous catalytic hydrogenation of the exomethylene unit at carbon 2 in the vitamin 11 performed efficiently in the presence of tris(triphenylphosphine)rhodium(I) chloride [Wilkinson's catalyst, (Ph₃P)₃RhCl]. Such reduction conditions allowed to reduce only C(2)=CH₂ unit leaving C(5)-C(8) butadiene moiety unaffected. The isolated material is an epimeric mixture (ca. 1:1) of 2-methyl-19-nor-vitamins

- 16 -

12 and 13 differing in configuration at C-2. The mixture can be used without separation or, if desired, the individual 2 α - and 2 β -isomers can be separated by an efficient HPLC system.

The C-20 epimerization was accomplished by the analogous coupling of the phosphine oxide 8 with protected (20S)-25-hydroxy Grundmann's ketone 15 (SCHEME II) and provided 19-nor-vitamin 16 which after hydrolysis of the hydroxy-protecting groups gave (20S)-1 α ,25-dihydroxy-2-methylene-19-nor-vitamin D₃ (17). Hydrogenation of 17 using Wilkinson's catalyst provided the expected mixture of the 2-methyl-19-nor-vitamin D analogs 18 and 19.

As noted above, other 2-methyl-19-nor-vitamin D analogs may be synthesized by the method disclosed herein. For example, 1 α -hydroxy-2-methylene-19-nor-vitamin D₃ can be obtained by providing the Grundmann's ketone (g); subsequent reduction of the A-ring exomethylene group in the formed compound can give the corresponding epimeric mixture of 1 α -hydroxy-2-methyl-19-nor-vitamin D₃ compounds.

This invention is described by the following illustrative examples. In these examples specific products identified by Arabic numerals (e.g. 1, 2, 3, etc) refer to the specific structures so identified in the preceding description and in the SCHEME I and SCHEME II.

EXAMPLE 1

25

Preparation of 1 α ,25-dihydroxy-2 α - and 1 α ,25-dihydroxy-2 β -methyl-19-nor-vitamin D₃ (12 and 13).

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Referring first to SCHEME 1 the starting methyl quinic derivative 1 was obtained from commercial (-)-quinic acid as described previously [Perlman et al., Tetrahedron Lett. 32, 7663 (1991) and DeLuca et al., U.S. Pat. No. 5,086,191]. 1: mp. 82-82.5 °C (from
5 hexane), ¹H NMR (CDCl₃) δ 0.098, 0.110, 0.142, and 0.159 (each 3H, each s, 4 x SiCH₃), 0.896 and 0.911 (9H and 9H, each s, 2 x Si-*t*-Bu), 1.820 (1H, dd, J = 13.1, 10.3 Hz), 2.02 (1H, ddd, J = 14.3, 4.3, 2.4 Hz), 2.09 (1H, dd, J = 14.3, 2.8 Hz), 2.19 (1H, ddd, J = 13.1, 4.4, 2.4 Hz), 2.31 (1H, d, J = 2.8 Hz, OH), 3.42 (1H, m; after D₂O dd, J = 8.6, 2.6 Hz), 3.77 (3H, s), 4.12
10 (1H, m), 4.37 (1H, m), 4.53 (1H, br s, OH).

(a) Oxidation of 4-hydroxy group in methyl quinic derivative 1.

(3R,5R)-3,5-Bis[(*tert*-butyldimethylsilyl)oxy]-1-hydroxy-4-oxocyclohexanecarboxylic Acid Methyl Ester (2). To a stirred
15 mixture of ruthenium(III) chloride hydrate (434 mg, 2.1 mmol) and sodium periodate (10.8 g, 50.6 mmol) in water (42 mL) was added a solution of methyl quinic 1 (6.09 g, 14 mmol) in CCl₄/CH₃CN (1:1, 64 mL). Vigorous stirring was continued for 8 h. Few drops of 2-propanol
20 were added. the mixture was poured into water and extracted with chloroform. The organic extracts were combined, washed with water, dried (MgSO₄) and evaporated to give a dark oily residue (ca. 5 g) which was purified by flash chromatography. Elution with hexane/ethyl acetate (8:2) gave pure, oily 4-ketone 2 (3.4 g, 56%): ¹H NMR (CDCl₃) δ
25 0.054, 0.091, 0.127, and 0.132 (each 3H, each s, 4 x SiCH₃), 0.908 and 0.913 (9H and 9H, each s, 2 x Si-*t*-Bu), 2.22 (1H, dd, J = 13.2, 11.7 Hz), 2.28 (1H, - dt, J = 14.9, 3.6 Hz), 2.37 (1H, dd, J = 14.9, 3.2 Hz), 2.55 (1H, ddd, J = 13.2, 6.4, 3.4 Hz), 3.79 (3H, s), 4.41 (1H, t, J ~ 3.5 Hz), 4.64 (1H,

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s, OH), 5.04 (1H, dd, $J = 11.7, 6.4$ Hz); MS m/z (relative intensity) no M^+ , 375 ($M^+ - t\text{-Bu}$, 32), 357 ($M^+ - t\text{-Bu} - \text{H}_2\text{O}$, 47), 243 (31), 225 (57), 73 (100).

5 (b) Wittig reaction of the 4-ketone 2.

(3R,5R)-3,5-Bis[(*tert*-butyldimethylsilyl)oxy]-1-hydroxy-4-methylenecyclohexanecarboxylic Acid Methyl Ester (3). To the methyltriphenylphosphonium bromide (2.813 g, 7.88 mmol) in anhydrous THF (32 mL) at 0 °C was added dropwise *n*-BuLi (2.5 M in hexanes, 6.0 mL, 15 mmol) under argon with stirring. Another portion of $\text{MePh}_3\text{P}^+\text{Br}^-$ (2.813 g, 7.88 mmol) was then added and the solution was stirred at 0 °C for 10 min and at room temperature for 40 min. The orange-red mixture was again cooled to 0 °C and a solution of 4-ketone 2 (1.558 g, 15 3.6 mmol) in anhydrous THF (16 + 2 mL) was syphoned to reaction flask during 20 min. The reaction mixture was stirred at 0 °C for 1 h and at room temperature for 3 h. The mixture was then carefully poured into brine cont. 1% HCl and extracted with ethyl acetate and benzene. The combined organic extracts were washed with diluted NaHCO_3 and 20 brine, dried (MgSO_4) and evaporated to give an orange oily residue (ca. 2.6 g) which was purified by flash chromatography. Elution with hexane/ethyl acetate (9:1) gave pure 4-methylene compound 3 as a colorless oil (368 mg, 24%): ^1H NMR (CDCl_3) δ 0.078, 0.083, 0.092, and 0.115 (each 3H, each s, 4 x SiCH_3), 0.889 and 0.920 (9H and 9H, each s, 2 x $\text{Si-}t\text{-Bu}$), 1.811 (1H, dd, $J = 12.6, 11.2$ Hz), 2.10 (2H, m), 2.31 (1H, dd, $J = 12.6, 5.1$ Hz), 3.76 (3H, s), 4.69 (1H, t, $J = 3.1$ Hz), 4.78 (1H, m), 4.96

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(2H, m; after D₂O 1H, br s), 5.17 (1H, t, J = 1.9 Hz); MS m/z (relative intensity) no M⁺, 373 (M⁺ - *t*-Bu, 57), 355 (M⁺ - *t*-Bu - H₂O, 13), 341 (19), 313 (25), 241 (33), 223 (37), 209 (56), 73 (100).

5 (c) Reduction of ester group in the 4-methylene compound 3.

[(3R,5R)-3,5-Bis[(*tert*-butyldimethylsilyl)oxy]-1-hydroxy-4-methylenecyclohexyl]methanol (4). (i) To a stirred solution of the ester 3 (90 mg, 0.21 mmol) in anhydrous THF (8 mL) lithium aluminum hydride (60 mg, 1.6 mmol) was added at 0 °C under argon. The cooling bath was removed after 1 h and the stirring was continued at 6 °C for 12 h and at room temperature for 6 h. The excess of the reagent was decomposed with saturated aq. Na₂SO₄, and the mixture was extracted with ethyl acetate and ether, dried (MgSO₄) and evaporated. Flash chromatography of the residue with hexane/ethyl acetate (9:1) afforded unreacted substrate (12 mg) and a pure, crystalline diol 4 (35 mg, 48% based on recovered ester 3): ¹H NMR (CDCl₃ + D₂O) δ 0.079, 0.091, 0.100, and 0.121 (each 3H, each s, 4 x SiCH₃), 0.895 and 0.927 (9H and 9H, each s, 2 x Si-*t*-Bu), 1.339 (1H, t, J ~ 12 Hz), 1.510 (1H, dd, J = 14.3, 2.7 Hz), 2.10 (2H, m), 3.29 and 3.40 (1H and 1H, each d, J = 11.0 Hz), 4.66 (1H, t, J ~ 2.8 Hz), 4.78 (1H, m), 4.92 (1H, t, J = 1.7 Hz), 5.13 (1H, t, J = 2.0 Hz); MS m/z (relative intensity) no M⁺, 345 (M⁺ - *t*-Bu, 8), 327 (M⁺ - *t*-Bu - H₂O, 22), 213 (28), 195 (11), 73 (100).

(ii) Diisobutylaluminum hydride (1.5 M in toluene, 2.0 mL, 3 mmol) was added to a solution of the ester 3 (215 mg, 0.5 mmol) in anhydrous ether (3 mL) at -78 °C under argon. The mixture was stirred at -78 °C for 3 h and at -24 °C for 1.5 h, diluted with ether (10 mL) and quenched by the slow addition of 2N potassium sodium tartrate. The solution was

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warmed to room temperature and stirred for 15 min, then poured into brine and extracted with ethyl acetate and ether. The organic extracts were combined, washed with diluted (ca. 1%) HCl, and brine, dried (MgSO₄) and evaporated. The crystalline residue was purified by flash chromatography. Elution with hexane/ethyl acetate (9:1) gave crystalline diol 4 (43 mg, 24%).

(d) Cleavage of the vicinal diol 4.

10 (3R,5R)-3,5-Bis[(*tert*-butyldimethylsilyl)oxy]-4-methylenecyclohexanone (5). Sodium periodate saturated water (2.2 mL) was added to a solution of the diol 4 (146 mg, 0.36 mmol) in methanol (9 mL) at 0 °C. The solution was stirred at 0 °C for 1 h, poured into brine and extracted with ether and benzene. The organic extracts
15 were combined, washed with brine, dried (MgSO₄) and evaporated. An oily residue was dissolved in hexane (1 mL) and applied on a silica Sep-Pak cartridge. Pure 4-methylenecyclohexanone derivative 5 (110 mg, 82%) was eluted with hexane/ethyl acetate (95:5) as a colorless oil: ¹H NMR (CDCl₃) δ 0.050 and 0.069 (6H and 6H, each s, 4 x SiCH₃), 0.881
20 (18H, s, 2 x Si-*t*-Bu), 2.45 (2H, ddd, J = 14.2, 6.9, 1.4 Hz), 2.64 (2H, ddd, J = 14.2, 4.6, 1.4 Hz), 4.69 (2H, dd, J = 6.9, 4.6 Hz), 5.16 (2H, s); MS m/z (relative intensity) no M⁺, 355 (M⁺ - Me, 3), 313 (M⁺ - *t*-Bu, 100), 73 (76).

25 (e) Preparation of the allylic ester 6.

[(3'R,5'R)-3',5'-Bis[(*tert*-butyldimethylsilyl)oxy]-4'-methylenecyclohexylidene]acetic Acid Methyl Ester (6). To a

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solution of diisopropylamine (37 μ L, 0.28 mmol) in anhydrous THF (200 μ L) was added *n*-BuLi (2.5 M in hexanes, 113 μ L, 0.28 mmol) under argon at -78 °C with stirring, and methyl(trimethylsilyl)acetate (46 μ L, 0.28 mmol) was then added. After 15 min, the keto compound 5 (49 mg, 0.132 mmol) in anhydrous THF (200 + 80 μ L) was added dropwise. The solution was stirred at -78 °C for 2 h and the reaction mixture was quenched with saturated NH₄Cl, poured into brine and extracted with ether and benzene. The combined organic extracts were washed with brine, dried (MgSO₄) and evaporated. The residue was dissolved in hexane (1 mL) and applied on a silica Sep-Pak cartridge. Elution with hexane and hexane/ethyl acetate (98:2) gave a pure allylic ester 6 (50 mg, 89%) as a colorless oil: ¹H NMR (CDCl₃) δ 0.039, 0.064, and 0.076 (6H, 3H, and 3H, each s, 4 x SiCH₃), 0.864 and 0.884 (9H and 9H, each s, 2 x Si-*t*-Bu), 2.26 (1H, dd, *J* = 12.8, 7.4 Hz), 2.47 (1H, dd, *J* = 12.8, 4.2 Hz), 2.98 (1H, dd, *J* = 13.3, 4.0 Hz), 3.06 (1H, dd, *J* = 13.3, 6.6 Hz), 3.69 (3H, s), 4.48 (2H, m), 4.99 (2H, s), 5.74 (1H, s); MS *m/z* (relative intensity) 426 (M⁺, 2), 411 (M⁺ - Me, 4), 369 (M⁺ - *t*-Bu, 100), 263 (69).

(f) Reduction of the allylic ester 6.

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2-[(3'*R*,5'*R*)-3',5'-Bis[(*tert*-butyldimethylsilyl)oxy]-4'-methylenecyclohexylidene]ethanol (7). Diisobutylaluminum hydride (1.5 M in toluene, 1.6 mL, 2.4 mmol) was slowly added to a stirred solution of the allylic ester 6 (143 mg, 0.33 mmol) in toluene/methylene chloride (2:1, 5.7 mL) at -78 °C under argon. Stirring was continued at -78 °C for 1 h and at -46 °C (cyclohexanone/dry ice bath) for 25 min. The mixture was quenched by the slow addition of

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potassium sodium tartrate (2N, 3 mL), aq. HCl (2N, 3 mL) and H₂O (12 mL), and then diluted with methylene chloride (12 mL) and extracted with ether and benzene. The organic extracts were combined, washed with diluted (ca. 1%) HCl, and brine, dried (MgSO₄) and evaporated. The
5 residue was purified by flash chromatography. Elution with hexane/ethyl acetate (9:1) gave crystalline allylic alcohol 7 (130 mg, 97%): ¹H NMR (CDCl₃) δ 0.038, 0.050, and 0.075 (3H, 3H, and 6H, each s, 4 x SiCH₃), 0.876 and 0.904 (9H and 9H, each s, 2 x Si-*t*-Bu), 2.12 (1H, dd, J = 12.3, 8.8 Hz), 2.23 (1H, dd, J = 13.3, 2.7 Hz), 2.45 (1H, dd, J =
10 12.3, 4.8 Hz), 2.51 (1H, dd, J = 13.3, 5.4 Hz), 4.04 (1H, m; after D₂O dd, J = 12.0, 7.0 Hz), 4.17 (1H, m; after D₂O dd, J = 12.0, 7.4 Hz), 4.38 (1H, m), 4.49 (1H, m), 4.95 (1H, br s), 5.05 (1H, t, J = 1.7 Hz), 5.69 (1H, ~ t, J = 7.2 Hz); MS m/z (relative intensity) 398 (M⁺, 2), 383 (M⁺ - Me, 2), 365 (M⁺ - Me - H₂O, 4), 341 (M⁺ - *t*-Bu, 78), 323 (M⁺ - *t*-Bu - H₂O, 10), 73
15 (100).

(g) Conversion of the allylic alcohol 7 into phosphine oxide 8.

[2-[(3'R,5'R)-3',5'-Bis[(*tert*-butyldimethylsilyl)oxy]-4'-
20 methylenecyclohexylidene]ethyl]diphenylphosphine Oxide (8).
To the allylic alcohol 7 (105 mg, 0.263 mmol) in anhydrous THF (2.4 mL) was added *n*-BuLi (2.5 M in hexanes, 105 μL, 0.263 mmol) under argon at 0 °C. Freshly recrystallized tosyl chloride (50.4 mg, 0.264 mmol) was dissolved in anhydrous THF (480 μL) and added to the allylic
25 alcohol-BuLi solution. The mixture was stirred at 0 °C for 5 min and set aside at 0 °C. In another dry flask with air replaced by argon, *n*-BuLi (2.5 M in hexanes, 210 μL, 0.525 mmol) was added to Ph₂PH (93 μL,

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0.534 mmol) in anhydrous THF (750 μ L) at 0 °C with stirring. The red solution was syphoned under argon pressure to the solution of tosylate until the orange color persisted (ca. 1/2 of the solution was added). The resulting mixture was stirred an additional 30 min at 0 °C, and
5 quenched by addition of H₂O (30 μ L). Solvents were evaporated under reduced pressure and the residue was redissolved in methylene chloride (2.4 mL) and stirred with 10% H₂O₂ at 0 °C for 1 h. The organic layer was separated, washed with cold aq. sodium sulfite and H₂O, dried (MgSO₄) and evaporated. The residue was subjected to flash
10 chromatography. Elution with benzene/ethyl acetate (6:4) gave semicrystalline phosphine oxide 8 (134 mg, 87%): ¹H NMR (CDCl₃) δ 0.002, 0.011, and 0.019 (3H, 3H, and 6H, each s, 4 x SiCH₃), 0.855 and 0.860 (9H and 9H, each s, 2 x Si-*t*-Bu), 2.0 - 2.1 (3H, br m), 2.34 (1H, m), 3.08 (1H, m), 3.19 (1H, m), 4.34 (2H, m), 4.90 and 4.94 (1H and 1H, each
15 s.), 5.35 (1H, ~ q, J = 7.4 Hz), 7.46 (4H, m), 7.52 (2H, m), 7.72 (4H, m); MS m/z (relative intensity) no M⁺, 581 (M⁺ - 1, 1), 567 (M⁺ - Me, 3), 525 (M⁺ - *t*-Bu, 100), 450 (10), 393 (48).

(h) Wittig-Horner coupling of protected 25-hydroxy Grundmann's
20 ketone 9 with the phosphine oxide 8.

1 α ,25-Dihydroxy-2-methylene-19-nor-vitamin D₃ (11). To a solution of phosphine oxide 8 (33.1 mg, 56.8 μ mol) in anhydrous THF (450 μ L) at 0 °C was slowly added *n*-BuLi (2.5 M in hexanes, 23 μ L, 57.5
25 μ mol) under argon with stirring. The solution turned deep orange. The mixture was cooled to -78 °C and a precooled (-78 °C) solution of protected hydroxy ketone 9 (9.0 mg, 22.8 μ mol), prepared according to

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published procedure [Sicinski et al., J. Med. Chem. 37, 3730 (1994)], in anhydrous THF (200 + 100 μ L) was slowly added. The mixture was stirred under argon at -78 °C for 1 h and at 0 °C for 18 h. Ethyl acetate was added, and the organic phase was washed with brine, dried (MgSO_4) and evaporated. The residue was dissolved in hexane and applied on a silica Sep-Pak cartridge, and washed with hexane/ethyl acetate (99:1, 20 mL) to give 19-nor-vitamin derivative **10** (13.5 mg, 78%). The Sep-Pak was then washed with hexane/ethyl acetate (96:4, 10 mL) to recover some unchanged C,D-ring ketone **9** (2 mg), and with ethyl acetate (10 mL) to recover diphenylphosphine oxide (20 mg). For analytical purpose a sample of protected vitamin **10** was further purified by HPLC (6.2 mm x 25 cm Zorbax-Sil column, 4 mL/min) using hexane/ethyl acetate (99.9:0.1) solvent system. Pure compound **10** was eluted at R_V 26 mL as a colorless oil: UV (in hexane) λ_{max} 244, 253, 263 nm; ^1H NMR (CDCl_3) δ 0.025, 0.049, 0.066, and 0.080 (each 3H, each s, 4 x SiCH_3), 0.546 (3H, s, 18- H_3), 0.565 (6H, q, J = 7.9 Hz, 3 x SiCH_2), 0.864 and 0.896 (9H and 9H, each s, 2 x $\text{Si-}t\text{-Bu}$), 0.931 (3H, d, J = 6.0 Hz, 21- H_3), 0.947 (9H, t, J = 7.9 Hz, 3 x SiCH_2CH_3), 1.188 (6H, s, 26- and 27- H_3), 2.00 (2H, m), 2.18 (1H, dd, J = 12.5, 8.5 Hz, 4 β -H), 2.33 (1H, dd, J = 13.1, 2.9 Hz, 10 β -H), 2.46 (1H, dd, J = 12.5, 4.5 Hz, 4 α -H), 2.52 (1H, dd, J = 13.1, 5.8 Hz, 10 α -H), 2.82 (1H, br d, J = 12 Hz, 9 β -H), 4.43 (2H, m, 1 β - and 3 α -H), 4.92 and 4.97 (1H and 1H, each s, $=\text{CH}_2$), 5.84 and 6.22 (1H and 1H, each d, J = 11.0 Hz, 7- and 6-H); MS m/z (relative intensity) 758 (M^+ , 17), 729 (M^+ - Et, 6), 701 (M^+ - $t\text{-Bu}$, 4), 626 (100), 494 (23), 366 (50), 73 (92).

Protected vitamin **10** (4.3 mg) was dissolved in benzene (150 μ L) and the resin (AG 50W-X4, 60 mg; prewashed with methanol) in

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methanol (800 μ L) was added. The mixture was stirred at room temperature under argon for 17 h, diluted with ethyl acetate/ether (1:1, 4 mL) and decanted. The resin was washed with ether (8 mL) and the combined organic phases washed with brine and saturated NaHCO_3 , dried (5 MgSO_4) and evaporated. The residue was purified by HPLC (6.2 mm x 25 cm Zorbax-Sil column, 4 mL/min) using hexane/2-propanol (9:1) solvent system. Analytically pure 2-methylene-19-nor-vitamin 11 (2.3 mg, 97%) was collected at R_V 29 mL (1 α ,25-dihydroxyvitamin D_3 was eluted at R_V 52 mL in the same system) as a white solid: UV (in EtOH) λ_{max} 10 243.5, 252, 262.5 nm; ^1H NMR (CDCl_3) δ 0.552 (3H, s, 18- H_3), 0.941 (3H, d, J = 6.4 Hz, 21- H_3), 1.222 (6H, s, 26- and 27- H_3), 2.01 (2H, m), 2.27 - 2.36 (2H, m), 2.58 (1H, m), 2.80 - 2.88 (2H, m), 4.49 (2H, m, 1 β - and 3 α -H), 5.10 and 5.11 (1H and 1H, each s, = CH_2), 5.89 and 6.37 (1H and 1H, each d, J = 11.3 Hz, 7- and 6-H); MS m/z (relative intensity) 416 (M^+ , 15 83), 398 (25), 384 (31), 380 (14), 351 (20), 313 (100).

(i) Hydrogenation of 2-methylene-19-nor-vitamin 11.

1 α ,25-Dihydroxy-2 α - and 1 α ,25-Dihydroxy-2 β -methyl-19-nor-
20 vitamin D_3 (12 and 13). Tris(triphenylphosphine)rhodium(I) chloride (2.3 mg, 2.5 μ mol) was added to dry benzene (2.5 mL) presaturated with hydrogen. The mixture was stirred at room temperature until a homogeneous solution was formed (ca. 45 min). A solution of vitamin 11 (1.0 mg, 2.4 μ mol) in dry benzene (0.5 mL) was then added and the
25 reaction was allowed to proceed under a continuous stream of hydrogen for 3 h. Benzene was removed under vacuum, and hexane/ethyl acetate (1:1, 2 mL) was added to the residue. The mixture was applied on a

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silica Sep-Pak and both 2-methyl vitamins were eluted with the same solvent system (20 mL). Further purification was achieved by HPLC (6.2 mm x 25 cm Zorbax-Sil column, 4 mL/min) using hexane/2-propanol (9:1) as a solvent system. The mixture (ca. 1:1) of 2-methyl-19-nor-
5 vitamins (2 α - and 2 β -epimers 12 and 13; 0.80 mg, 80%) gave a single peak at R_V 33 mL.

12 and 13: UV (in EtOH) λ_{max} 243, 251, 261.5 nm; ¹H NMR (CDCl₃) δ 0.536 and 0.548 (3H and 3H, each s, 2 x 18-H₃), 0.937 (6H, d, J = 6.3 Hz, 2 x 21-H₃), 1.133 and 1.144 (3H and 3H, each d, J ~ 6 Hz, 2 x 2-CH₃),
10 1.219 [12H, s, 2 x (26- and 27-H₃)], 2.60 (1H, dd, J = 13.0, 4.6 Hz), 2.80 (3H, m), 3.08 (1H, dd, J = 12.6, 4.0 Hz), 3.51 (1H, dt, J = 4.6, 10.2 Hz), 3.61 (1H, dt, J = 4.5, 9.1 Hz), 3.90 (1H, narr m), 3.96 (1H, narr m), 5.82, 5.87, 6.26, and 6.37 (each 1H, each d, J = 11.2 Hz); MS m/z (relative intensity) 418 (M⁺, 100), 400 (25), 385 (15), 289 (30), 245 (25).

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EXAMPLE 2

Preparation of (20S)-1 α ,25-dihydroxy-2 α - and (20S)-1 α ,25-dihydroxy-2 β -methyl-19-nor-vitamin D₃ (18 and 19).

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SCHEME II illustrates the preparation of protected (20S)-25-hydroxy Grundmann's ketone 15, its coupling with phosphine oxide 8 (obtained as described in Example 1) and selective hydrogenation of exomethylene group in 2-methylene compound 17.

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(a) Silylation of hydroxy ketone 14.

(20S)-25-[(Triethylsilyl)oxy]-des-A,B-cholestan-8-one (15).

A solution of the ketone 14 (Tetrionics, Inc.; 56 mg, 0.2 mmol) and
5 imidazole (65 mg, 0.95 mmol) in anhydrous DMF (1.2 mL) was treated
with triethylsilyl chloride (95 μ L, 0.56 mmol), and the mixture was
stirred at room temperature under argon for 4 h. Ethyl acetate was
added and water, and the organic layer was separated. The ethyl acetate
layer was washed with water and brine, dried (MgSO_4) and evaporated.
10 The residue was passed through a silica Sep-Pak cartridge in
hexane/ethyl acetate (9:1), and after evaporation, purified by HPLC (9.4
mm x 25 cm Zorbax-Sil column, 4 mL/min) using hexane/ethyl acetate
(9:1) solvent system. Pure protected hydroxy ketone 15 (55 mg, 70%)
was eluted at R_V 35 mL as a colorless oil: ^1H NMR (CDCl_3) δ 0.566 (6H, q,
15 $J = 7.9$ Hz, 3 x SiCH_2), 0.638 (3H, s, 18- H_3), 0.859 (3H, d, $J = 6.0$ Hz, 21- H_3),
0.947 (9H, t, $J = 7.9$ Hz, 3 x SiCH_2CH_3), 1.196 (6H, s, 26- and 27- H_3),
2.45 (1H, dd, $J = 11.4, 7.5$ Hz, 14 α -H).

(b) Wittig-Horner coupling of protected (20S)-25-hydroxy
20 Grundmann's ketone 15 with the phosphine oxide 8.

(20S)-1 α ,25-Dihydroxy-2-methylene-19-nor-vitamin D₃ (17).

To a solution of phosphine oxide 8 (15.8 mg, 27.1 μ mol) in anhydrous
THF (200 μ L) at 0 $^\circ\text{C}$ was slowly added n -BuLi (2.5 M in hexanes, 11 μ L,
25 27.5 μ mol) under argon with stirring. The solution turned deep orange.
The mixture was cooled to -78 $^\circ\text{C}$ and a precooled (-78 $^\circ\text{C}$) solution of
protected hydroxy ketone 15 (8.0 mg, 20.3 μ mol) in anhydrous THF (100

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μL) was slowly added. The mixture was stirred under argon at $-78\text{ }^{\circ}\text{C}$. for 1 h and at $0\text{ }^{\circ}\text{C}$ for 18 h. Ethyl acetate was added, and the organic phase was washed with brine, dried (MgSO_4) and evaporated. The residue was dissolved in hexane and applied on a silica Sep-Pak cartridge, and
5 washed with with hexane/ethyl acetate (99.5:0.5, 20 mL) to give 19-nor-vitamin derivative **16** (7 mg, 45%) as a colorless oil. The Sep-Pak was then washed with hexane/ethyl acetate (96:4, 10 mL) to recover some unchanged C,D-ring ketone **15** (4 mg), and with ethyl acetate (10 mL) to recover diphenylphosphine oxide (9 mg). For analytical purpose a
10 sample of protected vitamin **16** was further purified by HPLC (6.2 mm x 25 cm Zorbax-Sil column, 4 mL/min) using hexane/ethyl acetate (99.9:0.1) solvent system.

16: UV (in hexane) λ_{max} 244, 253.5, 263 nm; ^1H NMR (CDCl_3) δ 0.026, 0.049, 0.066, and 0.080 (each 3H, each s, 4 x SiCH_3), 0.541 (3H, s, 18-
15 H_3), 0.564 (6H, q, $J = 7.9\text{ Hz}$, 3 x SiCH_2), 0.848 (3H, d, $J = 6.5\text{ Hz}$, 21- H_3), 0.864 and 0.896 (9H and 9H, each s, 2 x $\text{Si-}t\text{-Bu}$), 0.945 (9H, t, $J = 7.9\text{ Hz}$, 3 x SiCH_2CH_3), 1.188 (6H, s, 26- and 27- H_3), 2.15 - 2.35 (4H, br m), 2.43 - 2.53 (3H, br m), 2.82 (1H, br d, $J = 12.9\text{ Hz}$, $9\beta\text{-H}$), 4.42 (2H, m, $1\beta\text{-}$ and $3\alpha\text{-H}$), 4.92 and 4.97 (1H and 1H, each s, $=\text{CH}_2$), 5.84 and 6.22
20 (1H and 1H, each d, $J = 11.1\text{ Hz}$, 7- and 6-H); MS m/z (relative intensity) 758 (M^+ , 33), 729 ($\text{M}^+ - \text{Et}$, 7), 701 ($\text{M}^+ - t\text{-Bu}$, 5), 626 (100), 494 (25), 366 (52), 75 (82), 73 (69).

Protected vitamin **16** (5.0 mg) was dissolved in benzene (160 μL) and the resin (AG 50W-X4, 70 mg; prewashed with methanol) in
25 methanol (900 μL) was added. The mixture was stirred at room temperature under argon for 19 h, diluted with ethyl acetate/ether (1:1, 4 mL) and decanted. The resin was washed with ether (8 mL) and the

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combined organic phases washed with brine and saturated NaHCO_3 , dried (MgSO_4) and evaporated. The residue was purified by HPLC (6.2 mm x 25 cm Zorbax-Sil column, 4 mL/min) using hexane/2-propanol (9:1) solvent system. Analytically pure 2-methylene-19-nor-vitamin 17 (2.6 mg, 95%) was collected at R_V 28 mL [(20*R*)-analog was eluted at R_V 29 mL and 1 α ,25-dihydroxyvitamin D_3 at R_V 52 mL in the same system] as a white solid: UV (in EtOH) λ_{max} 243.5, 252.5, 262.5 nm; ^1H NMR (CDCl_3) δ 0.551 (3H, s, 18- H_3), 0.858 (3H, d, J = 6.6 Hz, 21- H_3), 1.215 (6H, s, 26- and 27- H_3), 1.95 - 2.04 (2H, m), 2.27 - 2.35 (2H, m), 2.58 (1H, dd, J = 13.3, 3.7 Hz), 2.80 - 2.87 (2H, m), 4.49 (2H, m, 1 β - and 3 α -H), 5.09 and 5.11 (1H and 1H, each s, = CH_2), 5.89 and 6.36 (1H and 1H, each d, J = 11.3 Hz, 7- and 6-H); MS m/z (relative intensity) 416 (M^+ , 100), 398 (26), 380 (13), 366 (21), 313 (31).

15 (c) Hydrogenation of 2-methylene-19-nor-vitamin 17.

(20*S*)-1 α ,25-Dihydroxy-2 α - and 1 α ,25-Dihydroxy-2 β -methyl-19-nor-vitamin D_3 (18 and 19).

Tris(triphenylphosphine)rhodium(I) chloride (2.3 mg, 2.5 μmol) was added to dry benzene (2.5 mL) presaturated with hydrogen. The mixture was stirred at room temperature until a homogeneous solution was formed (ca. 45 min). A solution of vitamin 17 (1.0 mg, 2.4 μmol) in dry benzene (0.5 mL) was then added and the reaction was allowed to proceed under a continuous stream of hydrogen for 3 h. Benzene was removed under vacuum, and hexane/ethyl acetate (1:1, 2 mL) was added to the residue. The mixture was applied on a silica Sep-Pak and both 2-methyl vitamins were eluted with the same solvent system (20 mL).

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Further purification was achieved by HPLC (6.2 mm x 25 cm Zorbax-Sil column, 4 mL/min) using hexane/2-propanol (9:1) as a solvent system.

The mixture (ca. 1:1) of 2-methyl-19-nor-vitamins (2 α - and 2 β -epimers 18 and 19; 0.43 mg, 43%) gave a single peak at R_V 31 mL.

5 18 and 19: UV (in EtOH) λ_{max} 243, 251, 261 nm; ¹H NMR (CDCl₃) δ 0.534 and 0.546 (3H and 3H, each s, 2 x 18-H₃), 0.852 and 0.857 (3H and 3H, each d, J = 6.5 Hz, 2 x 21-H₃), 1.133 (3H, d, J = 6.7 Hz, 2-CH₃), 1.143 (3H, d, J = 6.5 Hz, 2-CH₃), 1.214 [12H, s, 2 x (26- and 27-H₃)], 2.60 (1H, dd, J = 12.7, 4.5 Hz), 2.80 (3H, m), 3.08 (1H, dd, J = 13.1, 4.3 Hz), 3.51
10 (1H, br m; after D₂O dt, J = 4.5, 10.0 Hz), 3.61 (1H, br m; after D₂O dt, J = 4.4, 9.2 Hz), 3.90 (1H, narr m), 3.96 (1H, narr m), 5.82, 5.87, 6.26, and 6.37 (each 1H, each d, J = 11.3 Hz); MS m/z (relative intensity) 418 (M⁺, 100), 400 (45), 385 (20), 289 (38), 245 (47).

15 BIOLOGICAL ACTIVITY OF 2-METHYL-SUBSTITUTED

19-NOR-1,25-(OH)₂D₃ COMPOUNDS AND THEIR 20S-ISOMERS

The introduction of a methyl group to the 2-position of 19-nor-1,25-(OH)₂D₃ or its 20S-isomer had little or no effect on binding to the porcine intestinal vitamin D receptor. All compounds bound equally
20 well to the porcine receptor including the standard 1,25-(OH)₂D₃ (Figure 1). It might be expected from these results that all of these compounds would have equivalent biological activity. Surprisingly, however, the 2-methyl substitutions produced highly selective analogs with their primary action on bone. When given for 7 days in a chronic
25 mode, the most potent compounds tested were a mixture of the S and R isomers of 2-methyl 19-nor-20S-1,25-(OH)₂D₃ (Table 1). When given at 130 pmol/day, the activity of this mixture of compounds on bone calcium mobilization (serum calcium) was much higher than that of the

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native hormone, possibly as high as 10 or 100 times higher. Under identical conditions, twice the dose of 1,25-(OH)₂D₃ gave a serum calcium value of 7.2 mg/100 ml, while a mixture of 2-methyl-(S and R)-19-nor-20S-1,25-(OH)₂D₃ gave a value of 9.6 mg/100 ml of serum calcium at the 130 pmol dose. When given at 260 pmol/day, this mixture produced the astounding value of 12.2 mg/100 ml of serum calcium at the expense of bone. To show its selectivity, these compounds produced no significant change in intestinal calcium transport at 130 pmol dose level while having a strong bone calcium mobilizing activity. At the higher dose, the 2-methyl-20S mixture did produce an intestinal transport response but gave an enormous bone mobilization response. A mixture of the S and R isomers of 2-methyl-19-nor-1,25-(OH)₂D₃ also had strong bone calcium mobilization at both dose levels but also showed no intestinal calcium transport activity. Thus, the 2-methyl-S and R derivatives given as a mixture showed strong preferential bone calcium mobilizing activity especially when the side chain was in the 20S-configuration. These results illustrate that the 2-methyl and the 20S-2-methyl derivatives of 19-nor-1,25-(OH)₂D₃ are selective for the mobilization of calcium from bone. Table 2 illustrates the response of both intestine and serum calcium to a single large dose of the various compounds; again, supporting the conclusions derived from Table 1.

The results in Figure 2 illustrate that a mixture of the S and R derivatives of 2-methyl-19-nor-20S-1,25-(OH)₂D₃ is extremely potent in inducing differentiation of HL-60 cells to the monocyte. The 2-methyl-S and R compounds had activity similar to 1,25-(OH)₂D₃. These results illustrate the potential of the 2-methyl-19-nor-20S-1,25-(OH)₂D₃ compounds as anti-cancer agents, especially against leukemia,

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colon cancer, breast cancer and prostate cancer, or as agents in the treatment of psoriasis.

Competitive binding of the analogs to the porcine intestinal receptor was carried out by the method described by Dame et al
5 (Biochemistry 25, 4523-4534, 1986).

The differentiation of HL-60 promyelocytic into monocytes was determined as described by Ostrem et al (J. Biol. Chem. 262, 14164-14171, 1987).

TABLE 1

**Response of Intestinal Calcium Transport and
Serum Calcium (Bone Calcium Mobilization) Activity
to Chronic Doses of 2-Methyl Derivatives of
19-Nor-1,25-(OH)₂D₃ and its 20S Isomers**

Group	Dose (pmol/day/7 days)	Intestinal Calcium Transport (S/M)	Serum Calcium (mg/100 ml)
Vitamin D Deficient	Vehicle	5.5 ± 0.2	5.1 ± 0.16
1,25-(OH) ₂ D ₃ Treated	260	6.2 ± 0.4	7.2 ± 0.5
2-Methyl (S and R) 19-Nor-1,25-(OH) ₂ D ₃	130 260	5.0 ± 0.3 5.3 ± 0.6	6.1 ± 0.1 6.7 ± 0.4
2-Methyl (S and R) 19-Nor-20S-1,25-(OH) ₂ D ₃	130 260	5.0 ± 0.9 6.9 ± 0.5	9.6 ± 0.1 12.2 ± 0.3

15

Male weanling rats were obtained from Sprague Dawley Co. (Indianapolis, IN) and fed a 0.47% calcium, 0.3% phosphorus vitamin D-deficient diet for 1 week and then given the same diet containing 0.02% calcium, 0.3% phosphorus for 2 weeks. During the last week they were
20 given the indicated dose of compound by intraperitoneal injection in 0.1 ml 95% propylene glycol and 5% ethanol each day for 7 days. The

control animals received only the 0.1ml of 95% propylene glycol, 5% ethanol. Twenty-four hours after the last dose, the rats were sacrificed and intestinal calcium transport was determined by everted sac technique as previously described and serum calcium determined by atomic absorption spectrometry on a model 3110 Perkin Elmer instrument (Norwalk, CT). There were 5 rats per group and the values represent mean \pm SEM.

TABLE 2

Response of Intestinal Calcium Transport and Serum Calcium (Bone Calcium Mobilization) Activity to a Single Dose of the 2-Methyl-Derivatives of 19-Nor-1,25-(OH)₂D₃ and its 20S Isomers

Group	Intestinal Calcium Transport (S/M)	Serum Calcium (mg/100 ml)
-D Control	4.2 \pm 0.3	4.7 \pm 0.1
1,25-(OH) ₂ D ₃	5.8 \pm 0.3	5.7 \pm 0.2
2-Methyl (S and R mixture)-19-Nor-1,25-(OH) ₂ D ₃	3.6 \pm 0.4	5.4 \pm 0.1
2-Methyl (S and R mixture)-19-Nor-20S-1,25-(OH) ₂ D ₃	6.7 \pm 0.6	8.1 \pm 0.3

Male Holtzman strain weanling rats were obtained from the Sprague Dawley Co. (Indianapolis, IN) and fed the 0.47% calcium, 0.3% phosphorus diet described by Suda et al. (J. Nutr. 100, 1049-1052, 1970) for 1 week and then fed the same diet containing 0.02% calcium and 0.3% phosphorus for 2 additional weeks. At this point, they received a single intrajugular injection of the indicated dose dissolved in 0.1 ml of 95% propylene glycol/5% ethanol. Twenty-four hours later

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they were sacrificed and intestinal calcium transport and serum calcium were determined as described in Table 1. The dose of the compounds was 650 pmol and there were 5 animals per group. The data are expressed as mean \pm SEM.

5 For treatment purposes, the novel compounds of this invention defined by formula I may be formulated for pharmaceutical applications as a solution in innocuous solvents, or as an emulsion, suspension or dispersion in suitable solvents or carriers, or as pills, tablets or capsules, together with solid carriers, according to conventional
10 methods known in the art. Any such formulations may also contain other pharmaceutically-acceptable and non-toxic excipients such as stabilizers, anti-oxidants, binders, coloring agents or emulsifying or taste-modifying agents.

The compounds may be administered orally, topically,
15 parenterally or transdermally. The compounds are advantageously administered by injection or by intravenous infusion or suitable sterile solutions, or in the form of liquid or solid doses via the alimentary canal, or in the form of creams, ointments, patches, or similar vehicles suitable for transdermal applications. Doses of from 0.1 μ g to 50 μ g per
20 day of the compounds are appropriate for treatment purposes, such doses being adjusted according to the disease to be treated, its severity and the response of the subject as is well understood in the art. Since the new compounds exhibit specificity of action, each may be suitably administered alone, or together with graded doses of
25 another active vitamin D compound -- e.g. 1 α -hydroxyvitamin D₂ or D₃, or 1 α ,25-dihydroxyvitamin D₃ -- in situations where different degrees of bone mineral mobilization and calcium transport stimulation is found to be advantageous.

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Compositions for use in the above-mentioned treatment of psoriasis and other malignancies comprise an effective amount of one or more 2-substituted-19-nor-vitamin D compound as defined by the above formula I as the active ingredient, and a suitable carrier. An effective amount of such compounds for use in accordance with this invention is from about 0.01 μ g to about 100 μ g per gm of composition, and may be administered topically, transdermally, orally or parenterally in dosages of from about 0.1 μ g/day to about 100 μ g/day.

The compounds may be formulated as creams, lotions, ointments, topical patches, pills, capsules or tablets, or in liquid form as solutions, emulsions, dispersions, or suspensions in pharmaceutically innocuous and acceptable solvent or oils, and such preparations may contain in addition other pharmaceutically innocuous or beneficial components, such as stabilizers, antioxidants, emulsifiers, coloring agents, binders or taste-modifying agents.

The compounds are advantageously administered in amounts sufficient to effect the differentiation of promyelocytes to normal macrophages. Dosages as described above are suitable, it being understood that the amounts given are to be adjusted in accordance with the severity of the disease, and the condition and response of the subject as is well understood in the art.

The formulations of the present invention comprise an active ingredient in association with a pharmaceutically acceptable carrier therefore and optionally other therapeutic ingredients. The carrier must be "acceptable" in the sense of being compatible with the other ingredients of the formulations and not deleterious to the recipient thereof.

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Formulations of the present invention suitable for oral administration may be in the form of discrete units as capsules, sachets, tablets or lozenges, each containing a predetermined amount of the active ingredient; in the form of a powder or granules; in the form of a solution or a suspension in an aqueous liquid or non-aqueous liquid; or in the form of an oil-in-water emulsion or a water-in-oil emulsion.

Formulations for rectal administration may be in the form of a suppository incorporating the active ingredient and carrier such as cocoa butter, or in the form of an enema.

Formulations suitable for parenteral administration conveniently comprise a sterile oily or aqueous preparation of the active ingredient which is preferably isotonic with the blood of the recipient.

Formulations suitable for topical administration include liquid or semi-liquid preparations such as liniments, lotions, applicants, oil-in-water or water-in-oil emulsions such as creams, ointments or pastes; or solutions or suspensions such as drops; or as sprays.

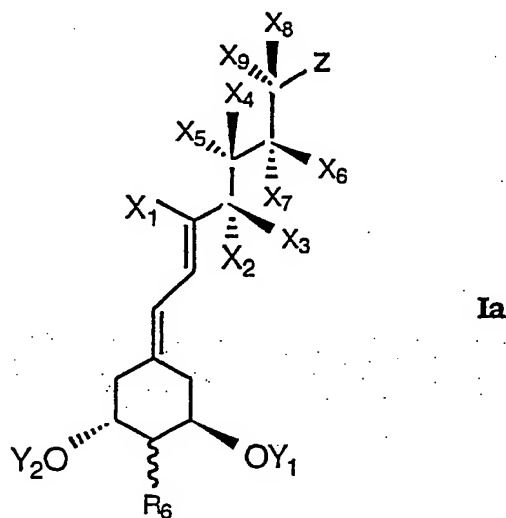
For asthma treatment, inhalation of powder, self-propelling or spray formulations, dispensed with a spray can, a nebulizer or an atomizer can be used. The formulations, when dispensed, preferably have a particle size in the range of 10 to 100 μ .

The formulations may conveniently be presented in dosage unit form and may be prepared by any of the methods well known in the art of pharmacy. By the term "dosage unit" is meant a unitary, i.e. a single dose which is capable of being administered to a patient as a physically and chemically stable unit dose comprising either the active ingredient as such or a mixture of it with solid or liquid pharmaceutical diluents or carriers.

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In its broadest application, the present invention relates to any 19-nor-2-alkyl analogs of vitamin D which have the vitamin D nucleus. By vitamin D nucleus, it is meant a central part consisting of a substituted chain of five carbon atoms which correspond to positions 8, 14, 13, 17 and 20 of vitamin D, and at the ends of which are connected at position 20 a structural moiety representing any of the typical side chains known for vitamin D type compounds (such as R as previously defined herein), and at position 8 the 5,7-diene moiety connected to the A-ring of an active 1 α -hydroxy vitamin D analog (as illustrated by formula I herein). Thus, various known modifications to the six-membered C-ring and the five-membered D-ring typically present in vitamin D, such as the lack of one or the other or both, are also embraced by the present invention.

Accordingly, compounds of the following formulae Ia, are along with those of formula I, also encompassed by the present invention:



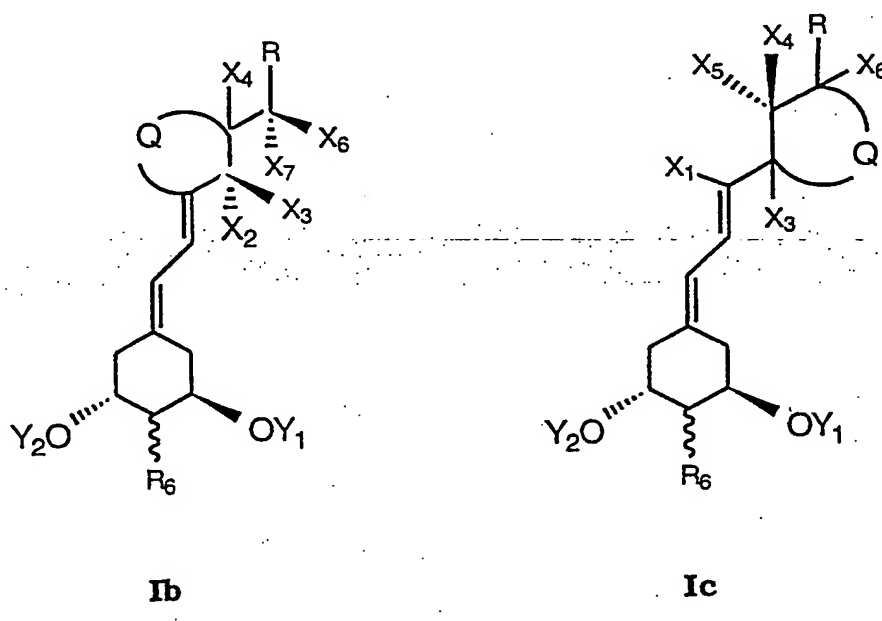
In the above formula Ia, the definitions of Y₁, Y₂, R₆, R₈ and Z are as previously set forth herein. With respect to X₁, X₂, X₃, X₄, X₅, X₆, X₇, X₈ and X₉, these substituents may be the same or different and are selected from hydrogen or lower alkyl, i.e. a C₁₋₅ alkyl such as methyl,

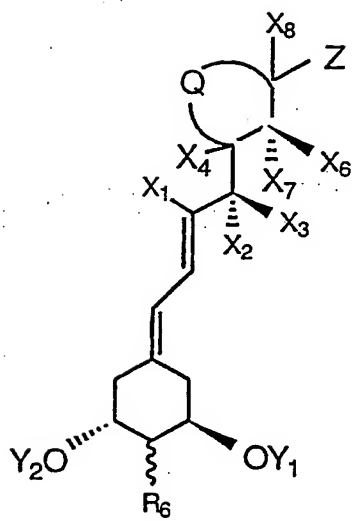
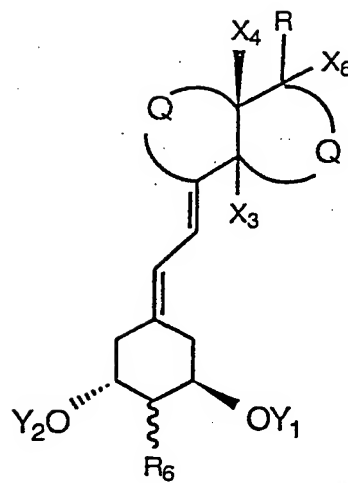
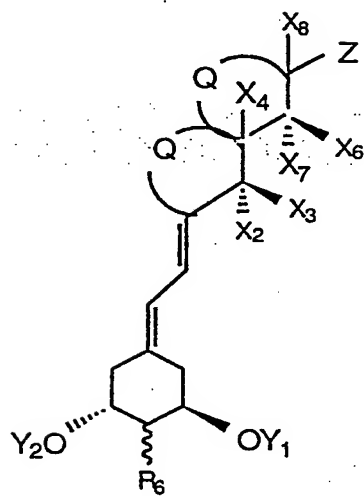
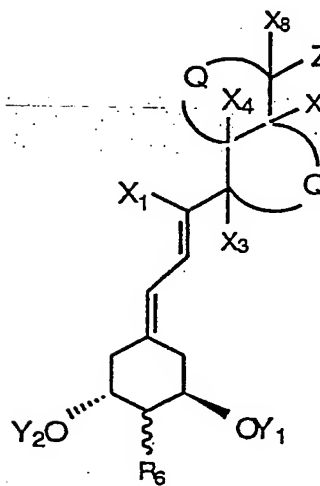
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ethyl or n-propyl. In addition, paired substituents X_1 and X_4 or X_5 , X_2 or X_3 and X_6 or X_7 , X_4 or X_5 and X_8 or X_9 , when taken together with the three adjacent carbon atoms of the central part of the compound, which correspond to positions 8, 14, 13 or 14, 13, 17 or 13, 17, 20 respectively, can be the same or different and form a saturated or unsaturated, substituted or unsubstituted, carbocyclic 3, 4, 5, 6 or 7 membered ring.

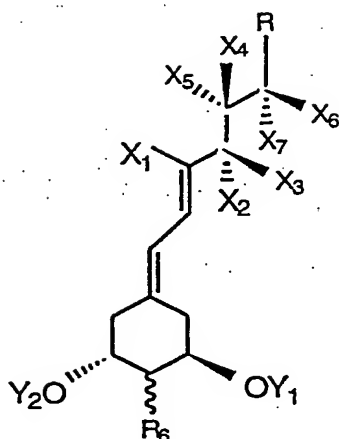
Preferred compounds of the present invention may be represented by one of the following formulae:



**Id****Ie****If****Ig**

25

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**1h**

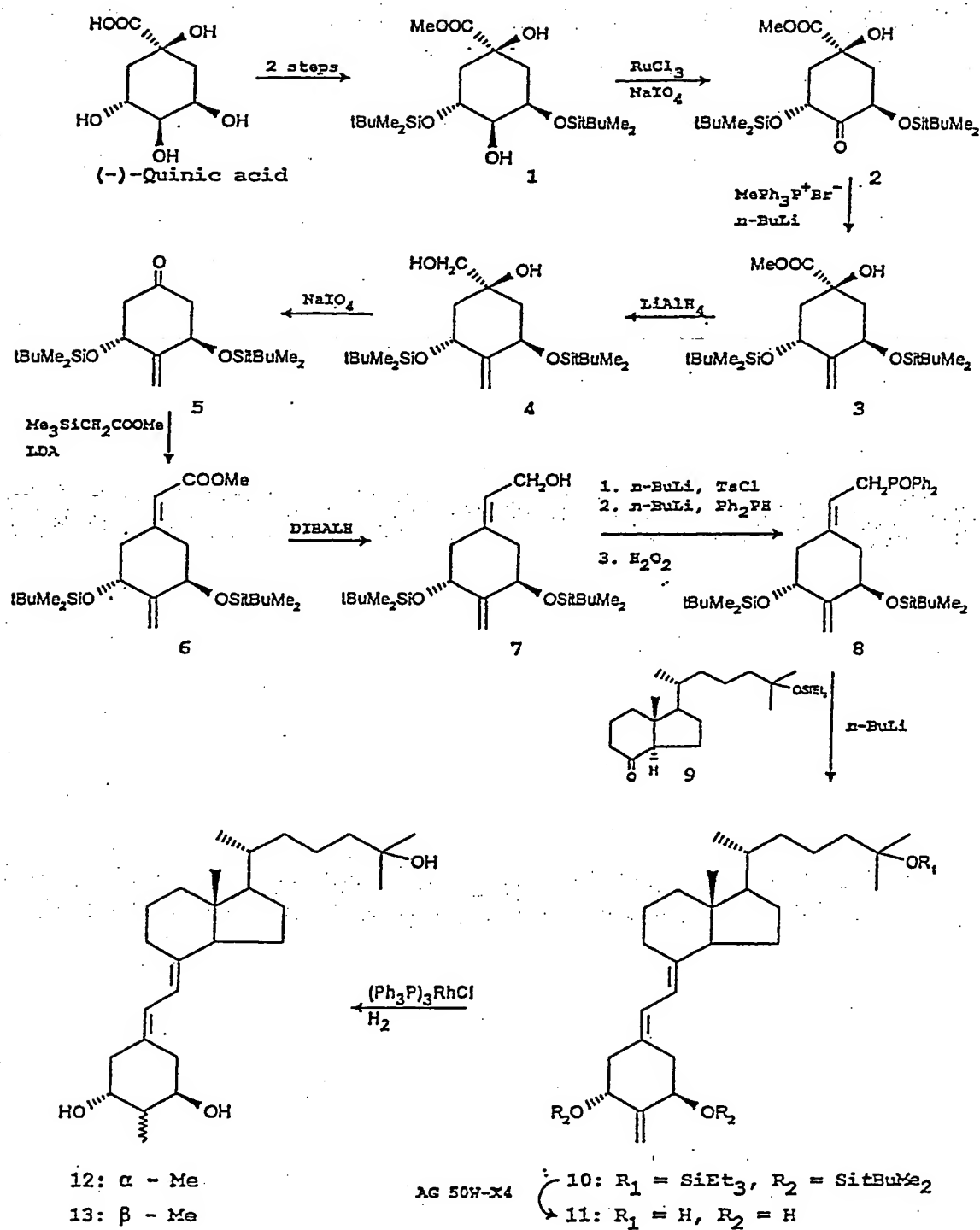
In the above formulae 1b, 1c, 1d, 1e, 1f, 1g and 1h, the definitions of Y_1 , Y_2 , R_6 , R , Z , X_1 , X_2 , X_3 , X_4 , X_5 , X_6 , X_7 and X_8 are as previously set forth herein.

- 15 The substituent Q represents a saturated or unsaturated, substituted or unsubstituted, hydrocarbon chain comprised of 0, 1, 2, 3 or 4 carbon atoms, but is preferably the group $-(CH_2)_k-$ where k is an integer equal to 2 or 3.

Methods for making compounds of formulae 1a-1h are known.

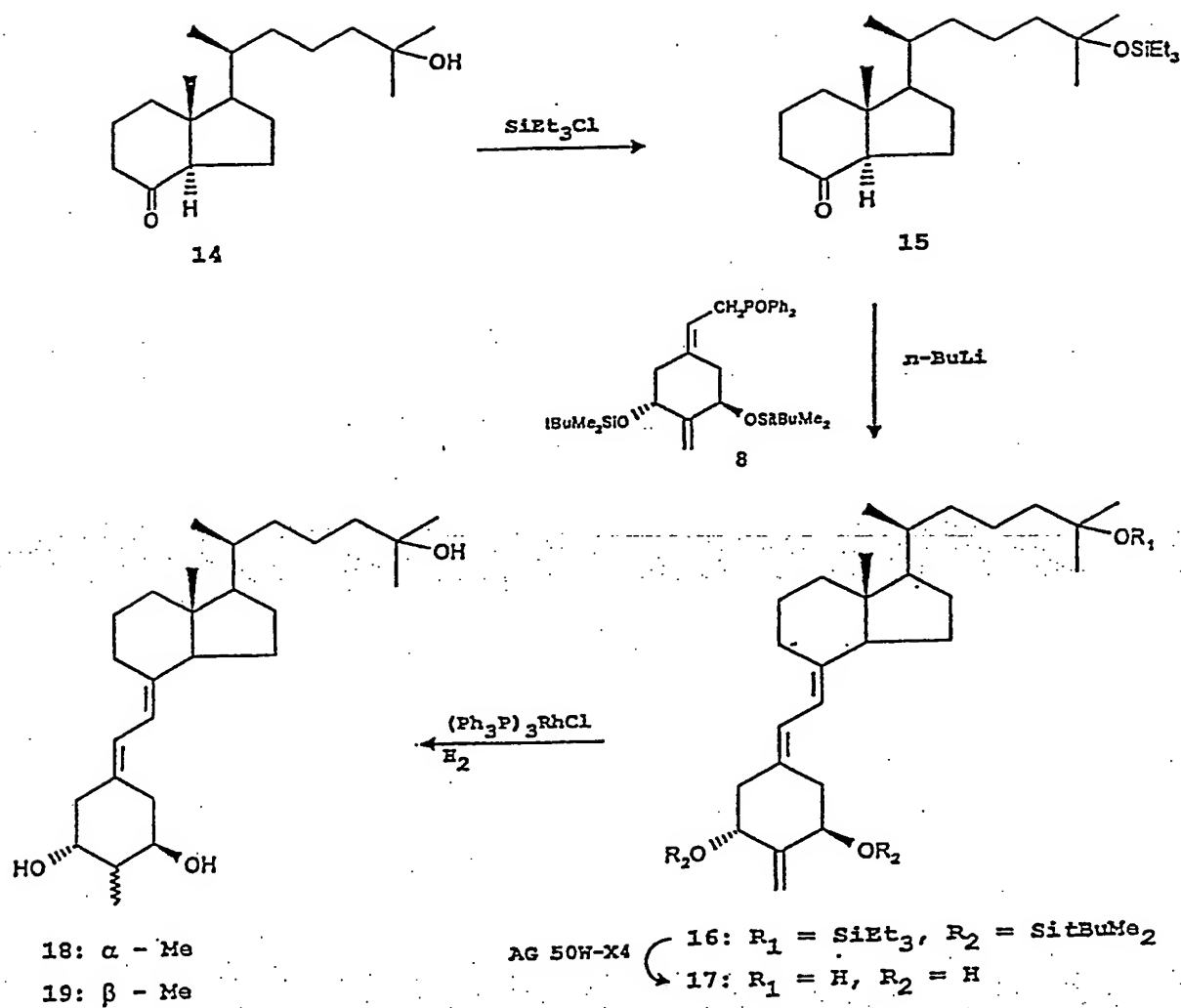
- 20 Specifically, reference is made to International Application Number PCT/EP94/02294 filed 7 July 1994 and published 19 January 1995 under International Publication Number WO95/01960.

SCHEME I



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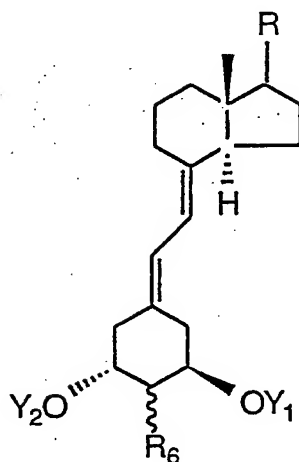
SCHEME II



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We claim:

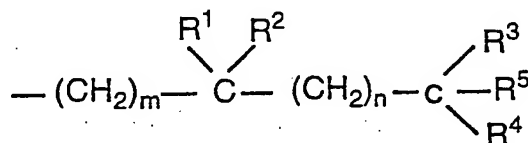
1. A compound having the formula:



where Y_1 and Y_2 , which may be the same or different, are each selected from the group consisting of hydrogen and a hydroxy-protecting group, R_6 is selected from alkyl, hydroxyalkyl and fluoroalkyl, and where the group R is represented by the structure:



where the stereochemical center at carbon 20 may have the R or S configuration, and where Z is selected from Y , $-OY$, $-CH_2OY$, $-C\equiv CY$ and $-CH=CHY$, where the double bond may have the cis or trans geometry, and where Y is selected from hydrogen, methyl, $-COR^5$ and a radical of the structure:



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where m and n, independently, represent the integers from 0 to 5,
 30 where R¹ is selected from hydrogen, deuterium, hydroxy, protected hydroxy, fluoro, trifluoromethyl, and C₁₋₅-alkyl, which may be straight chain or branched and, optionally, bear a hydroxy or protected-hydroxy substituent, and where each of R², R³, and R⁴, independently, is selected from deuterium, deuteroalkyl, hydrogen, fluoro, trifluoromethyl and C₁₋₅
 35 alkyl, which may be straight-chain or branched, and optionally, bear a hydroxy or protected-hydroxy substituent, and where R¹ and R², taken together, represent an oxo group, or an alkylidene group, =CR²R³, or the group -(CH₂)_p-, where p is an integer from 2 to 5, and where R³ and R⁴, taken together, represent an oxo group, or the group -(CH₂)_q-, where q is
 40 an integer from 2 to 5, and where R⁵ represents hydrogen, hydroxy, protected hydroxy, or C₁₋₅ alkyl and wherein any of the CH-groups at positions 20, 22, or 23 in the side chain may be replaced by a nitrogen atom, or where any of the groups -CH(CH₃)-, -CH(R³)-, or -CH(R²)- at positions 20, 22, and 23, respectively, may be replaced by an oxygen or
 45 sulfur atom.

2. The compound of claim 1 where R is a side chain of the formula

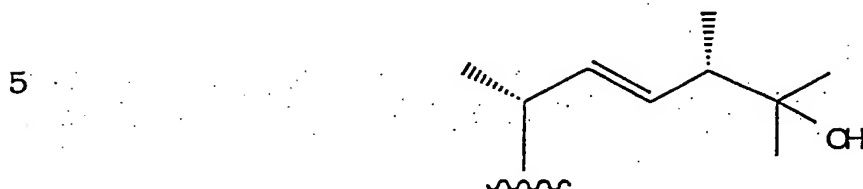


3 The compound of claim 1 where R is a side chain of the formula



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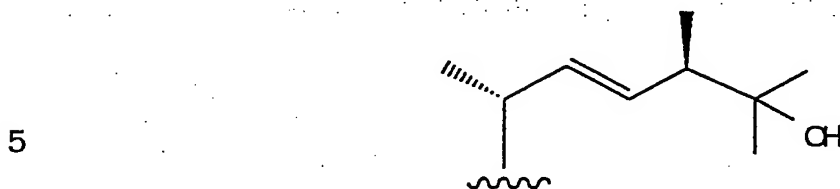
4. The compound of claim 1 where R is a side chain of the formula



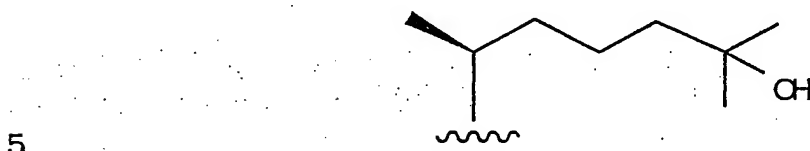
5. The compound of claim 1 where R is a side chain of the formula



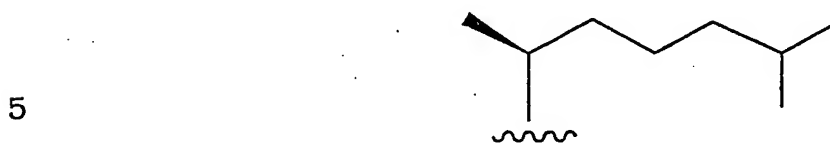
6. The compound of claim 1 where R is a side chain of the formula



7. The compound of claim 1 where R is a side chain of the formula

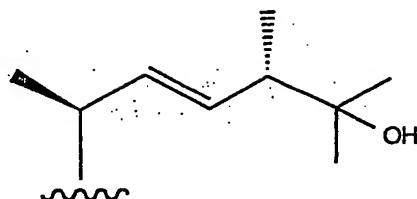


8. The compound of claim 1 where R is a side chain of the formula



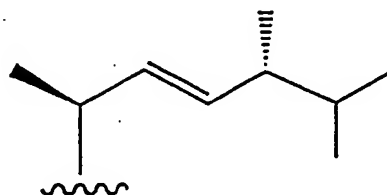
9. The compound of claim 1 where R is a side chain of the formula

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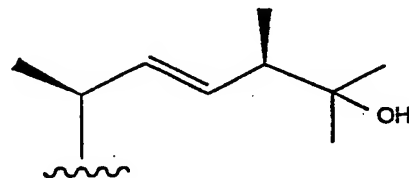
10. The compound of claim 1 where R is a side chain of the formula

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11. The compound of claim 1 where R is a side chain of the formula

5



12. 2(S)-methyl-19-nor-1 α ,25-dihydroxyvitamin D₃.

13. 2(R)-methyl-19-nor-1 α ,25-dihydroxyvitamin D₃.

14. 2(S)-methyl-19-nor-20(S)-1 α ,25-dihydroxyvitamin D₃.

15. 2(R)-methyl-19-nor-20(S)-1 α ,25-dihydroxyvitamin D₃.

16. A pharmaceutical composition containing at least one compound as claimed in claim 1 together with a pharmaceutically acceptable excipient.

17. The pharmaceutical composition of claim 16 containing 2(S)-methyl-19-nor-1 α ,25-dihydroxyvitamin D₃ in an amount from about 0.1 μ g to about 50 μ g.

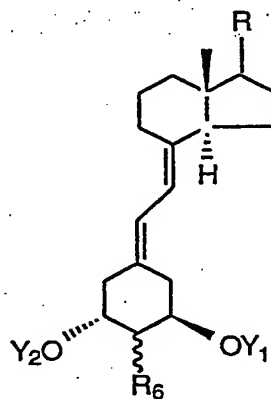
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18. The pharmaceutical composition of claim 16 containing 2(R)-methyl-19-nor-1 α ,25-dihydroxyvitamin D₃ in an amount from about 0.1 μ g to about 50 μ g.

19. The pharmaceutical composition of claim 16 containing 2(S)-methyl-19-nor-20(S)-1 α ,25-dihydroxyvitamin D₃ in an amount from about 0.1 μ g to about 50 μ g.

20. The pharmaceutical composition of claim 16 containing 2(R)-methyl-19-nor-20(S)-1 α ,25-dihydroxyvitamin D₃ in an amount from about 0.1 μ g to about 50 μ g.

21. A method of treating metabolic bone disease where it is desired to maintain or increase bone mass comprising administering to a patient with said disease an effective amount of a compound having the formula:

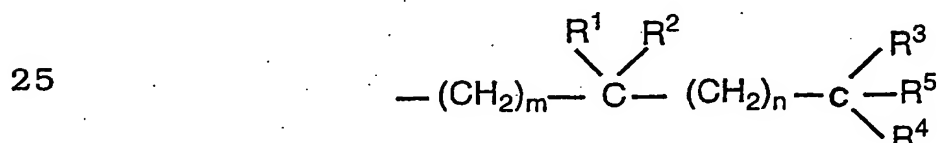


where Y₁ and Y₂, which may be the same or different, are each selected from the group consisting of hydrogen and a hydroxy-protecting group, R₆ is selected from alkyl, hydroxyalkyl and fluoroalkyl, and where the group R is represented by the structure:



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where the stereochemical center at carbon 20 may have the R or S configuration, and where Z is selected from Y, -OY, -CH₂OY, -C≡CY and -CH=CHY, where the double bond may have the cis or trans geometry, and where Y is selected from hydrogen, methyl, -COR⁵ and a radical of the structure:



where m and n, independently, represent the integers from 0 to 5, where R¹ is selected from hydrogen, deuterium, hydroxy, protected hydroxy, fluoro, trifluoromethyl, and C₁₋₅-alkyl, which may be straight chain or branched and, optionally, bear a hydroxy or protected-hydroxy substituent, and where each of R², R³, and R⁴, independently, is selected from deuterium, deuteroalkyl, hydrogen, fluoro, trifluoromethyl and C₁₋₅ alkyl, which may be straight-chain or branched, and optionally, bear a hydroxy or protected-hydroxy substituent, and where R¹ and R², taken together, represent an oxo group, or an alkylidene group, =CR²R³, or the group -(CH₂)_p-, where p is an integer from 2 to 5, and where R³ and R⁴, taken together, represent an oxo group, or the group -(CH₂)_q-, where q is an integer from 2 to 5, and where R⁵ represents hydrogen, hydroxy, protected hydroxy, or C₁₋₅ alkyl and wherein any of the CH-groups at positions 20, 22, or 23 in the side chain may be replaced by a nitrogen atom, or where any of the groups -CH(CH₃)-, -CH(R³)-, or -CH(R²)- at positions 20, 22, and 23, respectively, may be replaced by an oxygen or sulfur atom.

22. The method of claim 21 where the disease is senile osteoporosis.

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23. The method of claim 21 where the disease is postmenopausal osteoporosis.

24. The method of claim 21 where the disease is steroid-induced osteoporosis.

25. The method of claim 21 where the disease is low bone turnover osteoporosis.

26. The method of claim 21 where the disease is osteomalacia.

27. The method of claim 21 where the disease is renal osteodystrophy.

28. The method of claim 21 wherein the compound is administered orally.

29. The method of claim 21 wherein the compound is administered parenterally.

30. The method of claim 21 wherein the compound is administered transdermally.

31. The method of claim 21 wherein the compound is administered in a dosage of from 0.1 μ g to 50 μ g per day.

32. The method of claim 21 wherein the compound is 2(S)-methyl-19-nor-1 α ,25-dihydroxyvitamin D₃.

33. The method of claim 21 wherein the compound is 2(R)-methyl-19-nor-1 α ,25-dihydroxyvitamin D₃.

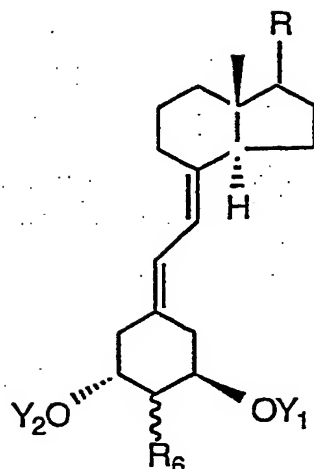
34. The method of claim 21 wherein the compound is 2(S)-methyl-19-nor-20(S)-1 α ,25-dihydroxyvitamin D₃.

35. The method of claim 21 wherein the compound is 2(R)-methyl-19-nor-20(S)-1 α ,25-dihydroxyvitamin D₃.

36. A method of treating psoriasis comprising administering to a patient with said disease an effective amount of a compound having the formula:

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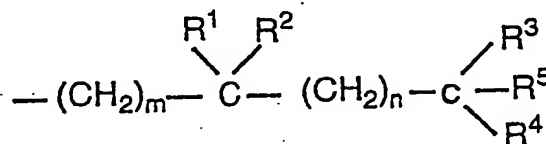
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where Y_1 and Y_2 , which may be the same or different, are each selected from the group consisting of hydrogen and a hydroxy-protecting group,
 15 R_6 is selected from alkyl, hydroxyalkyl and fluoroalkyl, and where the group R is represented by the structure:



where the stereochemical center at carbon 20 may have the R or S configuration, and where Z is selected from Y, -OY, -CH₂OY, -C≡CY and -CH=CHY, where the double bond may have the cis or trans geometry,
 25 and where Y is selected from hydrogen, methyl, -COR⁵ and a radical of the structure:



30 where m and n, independently, represent the integers from 0 to 5,
 where R^1 is selected from hydrogen, deuterium, hydroxy, protected

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hydroxy, fluoro, trifluoromethyl, and C₁₋₅-alkyl, which may be straight chain or branched and, optionally, bear a hydroxy or protected-hydroxy substituent, and where each of R², R³, and R⁴, independently, is selected
35 from deuterium, deuteroalkyl, hydrogen, fluoro, trifluoromethyl and C₁₋₅ alkyl, which may be straight-chain or branched, and optionally, bear a hydroxy or protected-hydroxy substituent, and where R¹ and R², taken together, represent an oxo group, or an alkylidene group, =CR²R³, or the group -(CH₂)_p-, where p is an integer from 2 to 5, and where R³ and R⁴,
40 taken together, represent an oxo group, or the group -(CH₂)_q-, where q is an integer from 2 to 5, and where R⁵ represents hydrogen, hydroxy, protected hydroxy, or C₁₋₅ alkyl and wherein any of the CH-groups at positions 20, 22, or 23 in the side chain may be replaced by a nitrogen atom, or where any of the groups -CH(CH₃)-, -CH(R³)-, or -CH(R²)- at
45 positions 20, 22, and 23, respectively, may be replaced by an oxygen or sulfur atom.

37. The method of claim 36 wherein the compound is 2(S)-methyl-19-nor-1 α ,25-dihydroxyvitamin D₃.

38. The method of claim 36 wherein the compound is 2(R)-methyl-19-nor-1 α ,25-dihydroxyvitamin D₃.

39. The method of claim 36 wherein the compound is 2(S)-methyl-19-nor-20(S)-1 α ,25-dihydroxyvitamin D₃.

40. The method of claim 36 wherein the compound is 2(R)-methyl-19-nor-20(S)-1 α ,25-dihydroxyvitamin D₃.

41. The method of claim 36 wherein said effective amount comprises about 0.01 μ g/day to about 100 μ g/day of said compound.

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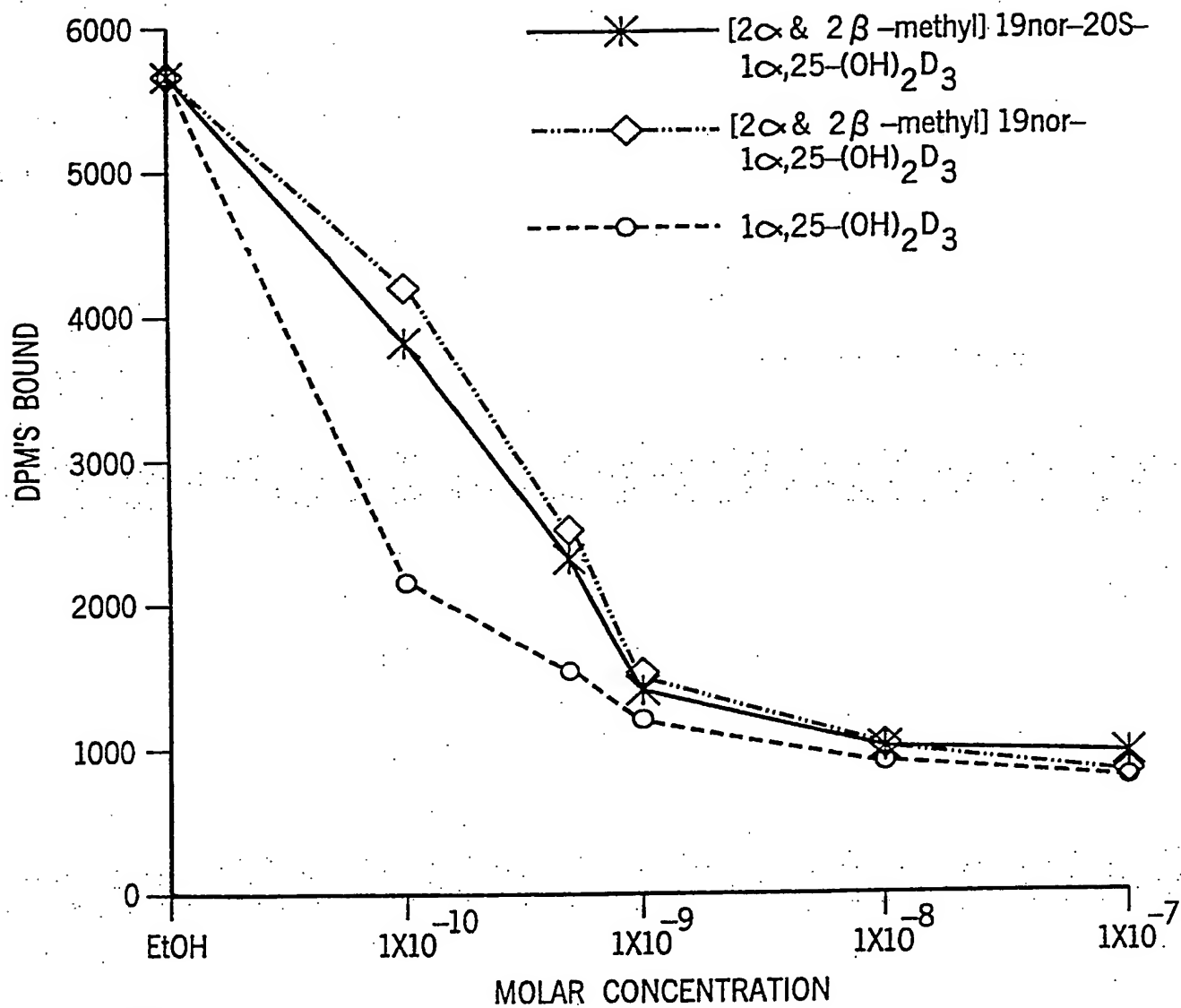


FIG. 1

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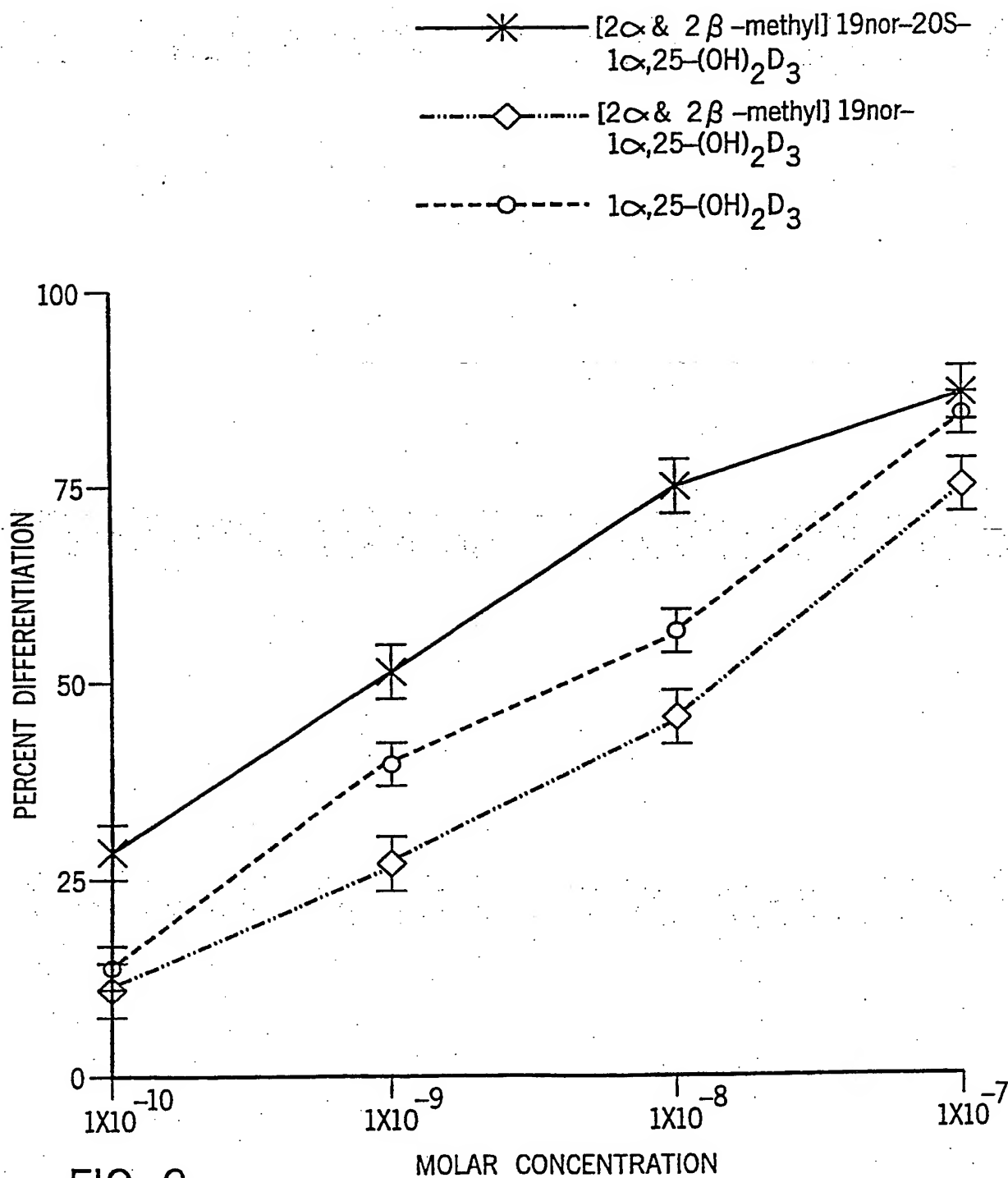


FIG. 2

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INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 98/02975

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 C07C401/00 A61K31/59

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 C07C A61K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 536 713 A (H.F. DELUCA ET AL) 16 July 1996 cited in the application see column 17, line 38 - column 19, line 42; schemes I, IV; ---	1-3,16, 23,25, 28-31, 36,41
A	CHEMICAL ABSTRACTS, vol. 121, no. 21, 21 November 1994 Columbus, Ohio, US; abstract no. 256121m, XP002066055 see abstract; RN 158388-02-4, 158387-98-5, 158388-05-7, 158388-07-9, 158388-09-1, 158388-11-5, 158388-13-7, 158388-15-9, 158388-21-7, 158388-23-9, 158388-25-1 & JP 06 041 059 A (CHUGAI PHARMACEUTICAL CO LTD) 15 February 1994 ---	1-3,16, 21
-/-		

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 666 634 A (K. MIYAMOTO ET AL) 19 May 1987 cited in the application see column 1, lines 6-13; claims ---	1-3,16, 21,26
A	WO 96 01811 A (THE JOHN-HOPKINS UNIVERSITY) 25 January 1996 see pages 3-4; page 20, line 1 - page 21, line 6; claims 1-6 -----	1,2,16, 21,23

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 98/02975

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☒ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
Although claims 21-41 are directed to a method of treatment of the human/animal body, the search has been carried out and based on the alleged effects of the compound/composition.
2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
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4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 98/02975

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5536713 A	16-07-1996	DE 69400495 D DE 69400495 T EP 0619306 A JP 6321894 A	17-10-1996 30-04-1997 12-10-1994 22-11-1994
US 4666634 A	19-05-1987	CA 1330806 A CN 85108857 A,B DK 561485 A,B, EP 0184206 A JP 1894284 C JP 6023185 B JP 61267549 A KR 9402981 B	19-07-1994 09-07-1986 06-06-1986 11-06-1986 26-12-1994 30-03-1994 27-11-1986 09-04-1994
WO 9601811 A	25-01-1996	NONE	

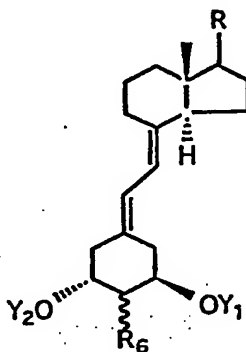
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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : C07C 401/00, A61K 31/59	A1	(11) International Publication Number: WO 98/41500 (43) International Publication Date: 24 September 1998 (24.09.98)
<p>(21) International Application Number: PCT/US98/02975</p> <p>(22) International Filing Date: 11 February 1998 (11.02.98)</p> <p>(30) Priority Data: 08/819,694 17 March 1997 (17.03.97) US</p> <p>(71) Applicant: WISCONSIN ALUMNI RESEARCH FOUNDATION [US/US]; 614 North Walnut Street, Madison, WI 53705 (US).</p> <p>(72) Inventors: DELUCA, Hector, F.; 1809 Highway BB, Deerfield, WI 53531 (US). SICINSKI, Rafal, R.; ul. Waszyngtona 33 m. 150, PL-04-030 Warsaw (PL).</p> <p>(74) Agents: WOZNY, Thomas, M. et al.; Andrus, Scales, Starke & Sawall, LLP, Suite 1100, 100 East Wisconsin Avenue, Milwaukee, WI 53202 (US).</p>	<p>(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GW, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).</p> <p>Published With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</p>	

(54) Title: 2-ALKYL-19-NOR-VITAMIN D COMPOUNDS



(1)

(57) Abstract

This invention provides a novel class of vitamin D related compounds, namely, the 2-alkyl-19-nor-vitamin D derivatives, as well as a general method for their chemical synthesis. The compounds have formula (I), where Y₁ and Y₂, which may be the same or different, are each selected from the group consisting of hydrogen and a hydroxy-protecting group, R₆ is selected from the group consisting of alkyl, hydroxyalkyl and fluoroalkyl, and where the group R represents any of the typical side chains known for vitamin D type compounds. These 2-substituted compounds are characterized by low intestinal calcium transport activity and high bone calcium mobilization activity resulting in novel therapeutic agents for the treatment of diseases where bone formation is desired, particularly low bone turnover osteoporosis. These compounds also exhibit pronounced activity in arresting the proliferation of undifferentiated cells and inducing their differentiation to the monocyte thus evidencing use as anti-cancer agents and for the treatment of diseases such as psoriasis.

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2-ALKYL-19-NOR-VITAMIN D COMPOUNDS

CROSS-REFERENCE TO RELATED APPLICATIONS

STATEMENT REGARDING FEDERALLY SPONSERED RESEARCH OR DEVELOPMENT

BACKGROUND OF THE INVENTION

5 This patent invention relates to vitamin D compounds, and more particularly to vitamin D derivatives substituted at the carbon 2 position.

The natural hormone, $1\alpha,25$ -dihydroxyvitamin D_3 and its analog in ergosterol series, i.e. $1\alpha,25$ -dihydroxyvitamin D_2 are known to be highly potent regulators of calcium homeostasis in animals and humans, and more recently their activity in cellular differentiation has been established, Ostrem et al., Proc. Natl. Acad. Sci. USA, 84, 2610 (1987). Many structural analogs of these metabolites have been prepared and tested, including 1α -hydroxyvitamin D_3 , 1α -hydroxyvitamin D_2 , various side chain homologated vitamins and fluorinated analogs. Some of these compounds exhibit an interesting separation of activities in cell differentiation and calcium regulation. This difference in activity may be useful in the treatment of a variety of diseases as renal osteodystrophy, vitamin D-resistant rickets, osteoporosis, psoriasis, and certain malignancies.

25 Recently, a new class of vitamin D analogs has been discovered; i.e. the so called 19-nor-vitamin D compounds, which are characterized by the replacement of the A-ring exocyclic methylene group (carbon 19), typical of the vitamin D system, by two hydrogen atoms. Biological

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testing of such 19-nor-analogs (e.g., $1\alpha,25$ -dihydroxy-19-nor-vitamin D_3) revealed a selective activity profile with high potency in inducing cellular differentiation, and very low calcium mobilizing activity. Thus, these compounds are potentially useful as therapeutic agents for the treatment of malignancies, or the treatment of various skin disorders. Two different methods of synthesis of such 19-nor-vitamin D analogs have been described (Perlman et al., Tetrahedron Lett. 31, 1823 (1990); Perlman et al., Tetrahedron Lett. 32, 7663 (1991), and DeLuca et al., U.S. Pat. No. 5,086,191).

10 In U.S. Pat. No. 4,666,634, 2β -hydroxy and alkoxy (e.g., ED-71) analogs of $1\alpha,25$ -dihydroxyvitamin D_3 have been described and examined by Chugai group as potential drugs for osteoporosis and as antitumor agents. See also Okano et al., Biochem. Biophys. Res. Commun. 163, 1444 (1989). Other 2-substituted (with hydroxyalkyl, e.g., ED-120, and fluoroalkyl groups) A-ring analogs of $1\alpha,25$ -dihydroxyvitamin D_3 have also been prepared and tested (Miyamoto et al., Chem. Pharm. Bull. 41, 1111 (1993); Nishii et al., Osteoporosis Int. Suppl. 1, 190 (1993); Posner et al., J. Org. Chem. 59, 7855 (1994), and J. Org. Chem. 60, 4617 (1995)).

20 Recently, 2-substituted analogs of $1\alpha,25$ -dihydroxy-19-norvitamin D_3 have also been synthesized, i.e. compounds substituted at 2-position with hydroxy or alkoxy groups (DeLuca et al., U.S. Pat. No. 5,536,713), which exhibit interesting and selective activity profiles. All these studies indicate that binding sites in vitamin D receptors can accomodate different substituents at C-2 in the synthesized vitamin D analogs.

25 In a continuing effort to explore the 19-nor class of pharmacologically important vitamin D compounds, their analogs which

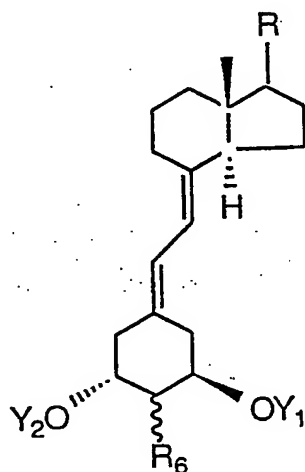
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are characterized by the presence of an alkyl (particularly methyl) substituent at the carbon 2 (C-2), i.e. 2-alkyl-19-nor-vitamin D compounds, and particularly 2-methyl-19-nor-vitamin D compounds, have now been synthesized and tested. Such vitamin D analogs seemed interesting targets because the relatively small alkyl (particularly methyl) group at C-2 should not interfere with vitamin D receptor. On the other hand it is obvious that a change of conformation of the cyclohexanediol ring A can be expected for these new analogs.

SUMMARY OF THE INVENTION

A class of 1α -hydroxylated vitamin D compounds not known heretofore are the 19-nor-vitamin D analogs having an alkyl (particularly methyl) group at the 2-position, i.e. 2-alkyl-19-nor-vitamin D compounds, particularly 2-methyl-19-nor-vitamin D compounds.

Structurally these novel analogs are characterized by the general formula I shown below:



where Y₁ and Y₂, which may be the same or different, are each selected from the group consisting of hydrogen and a hydroxy-protecting group,

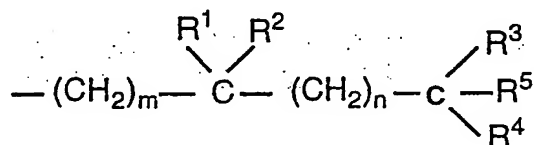
- 4 -

R₆ is selected from the group consisting of alkyl, hydroxyalkyl and fluoroalkyl, and where the group R represents any of the typical side chains known for vitamin D type compounds.

More specifically R can represent a saturated or unsaturated hydrocarbon radical of 1 to 35 carbons, that may be straight-chain, branched or cyclic and that may contain one or more additional substituents, such as hydroxy- or protected-hydroxy groups, fluoro, carbonyl, ester, epoxy, amino or other heteroatomic groups. Preferred side chains of this type are represented by the structure below



where the stereochemical center (corresponding to C-20 in steroid numbering) may have the R or S configuration, (i.e. either the natural configuration about carbon 20 or the 20-epi configuration), and where Z is selected from Y, -OY, -CH₂OY, -C≡CY and -CH=CHY, where the double bond may have the cis or trans geometry, and where Y is selected from hydrogen, methyl, -COR⁵ and a radical of the structure:



where m and n, independently, represent the integers from 0 to 5,

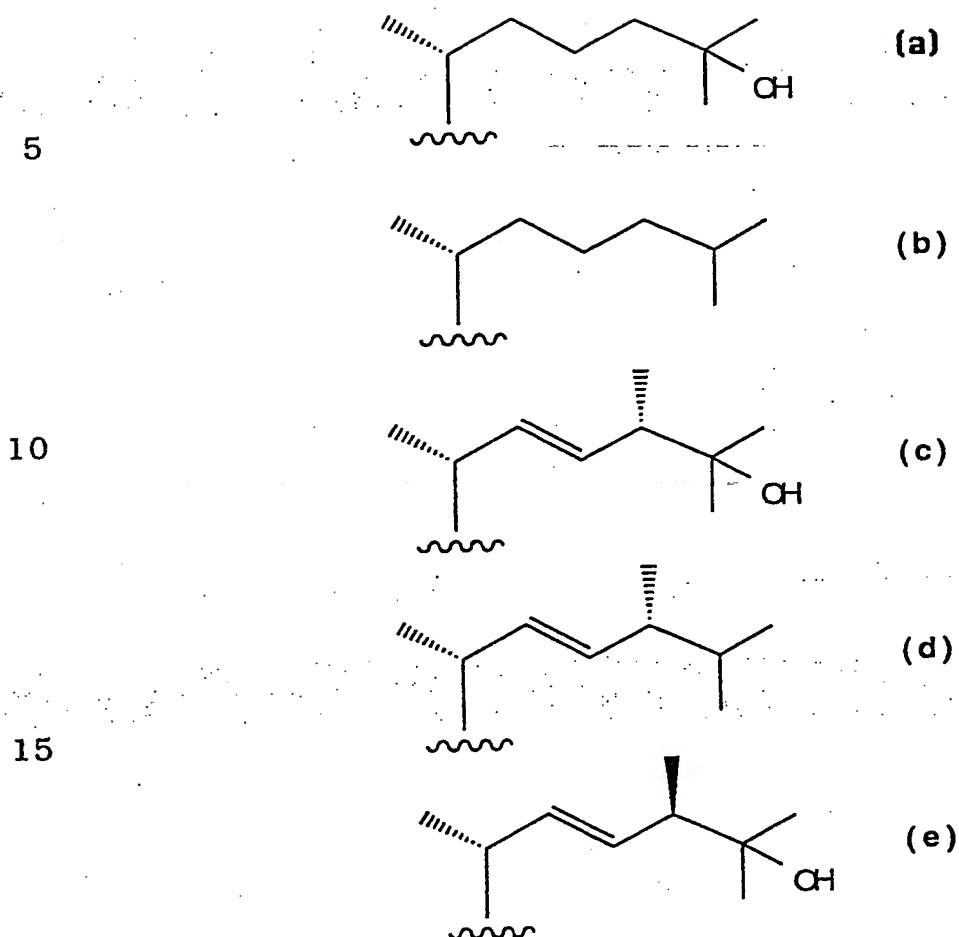
where R¹ is selected from hydrogen, deuterium, hydroxy, protected hydroxy, fluoro, trifluoromethyl, and C₁₋₅-alkyl, which may be straight

- 5 -

chain or branched and, optionally, bear a hydroxy or protected-hydroxy substituent, and where each of R², R³, and R⁴, independently, is selected from deuterium, deuteroalkyl, hydrogen, fluoro, trifluoromethyl and C₁₋₅ alkyl, which may be straight-chain or branched, and optionally, bear a hydroxy or protected-hydroxy substituent, and where R¹ and R², taken together, represent an oxo group, or an alkylidene group, =CR²R³, or the group -(CH₂)_p-, where p is an integer from 2 to 5, and where R³ and R⁴, taken together, represent an oxo group, or the group -(CH₂)_q-, where q is an integer from 2 to 5, and where R⁵ represents hydrogen, hydroxy, protected hydroxy, or C₁₋₅ alkyl and wherein any of the CH-groups at positions 20, 22, or 23 in the side chain may be replaced by a nitrogen atom, or where any of the groups -CH(CH₃)-, -CH(R³)-, or -CH(R²)- at positions 20, 22, and 23, respectively, may be replaced by an oxygen or sulfur atom.

15 The wavy lines to the substituents at C-2 and at C-20 indicate that the carbon 2 and carbon 20 may have either the R or S configuration.

Specific important examples of side chains with natural 20R-configuration are the structures represented by formulas (a), (b), (c), (d) and (e) below. i.e. the side chain as it occurs in 25-hydroxyvitamin D₃ (a); vitamin D₃ (b); 25-hydroxyvitamin D₂ (c); vitamin D₂ (d); and the C-24 epimer of 25-hydroxyvitamin D₂ (e):



20 The above novel compounds exhibit a desired, and highly advantageous, pattern of biological activity. These compounds are characterized by little, if any intestinal calcium transport activity, as compared to that of $1\alpha,25$ -dihydroxyvitamin D_3 , while exhibiting relatively high activity, as compared to $1\alpha,25$ -dihydroxyvitamin D_3 , in

25 their ability to mobilize calcium from bone. Hence, these compounds are highly specific in their calcemic activity. Their preferential activity on mobilizing calcium from bone and reduced intestinal calcium transport activity allows the in vivo administration of these

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compounds for the treatment of metabolic bone diseases where bone loss is a major concern. Because of their preferential calcemic activity on bone, these compounds would be preferred therapeutic agents for the treatment of diseases where bone formation is desired, such as osteoporosis, especially low bone turnover osteoporosis, steroid induced osteoporosis, senile osteoporosis or postmenopausal osteoporosis, as well as osteomalacia and renal osteodystrophy. The treatment may be transdermal, oral or parenteral. The compounds may be present in a composition in an amount from about 0.1 μ g/gm to about 50 μ g/gm of the composition, and may be administered in dosages of from about 0.1 μ g/day to about 50 μ g/day.

The compounds of the invention are also especially suited for treatment and prophylaxis of human disorders which are characterized by an imbalance in the immune system, e.g. in autoimmune diseases, including multiple sclerosis, diabetes mellitus, host versus graft reaction, and rejection of transplants; and additionally for the treatment of inflammatory diseases, such as rheumatoid arthritis and asthma, as well as the improvement of bone fracture healing and improved bone grafts. Acne, alopecia, skin conditions such as dry skin (lack of dermal hydration), undue skin slackness (insufficient skin firmness), insufficient sebum secretion and wrinkles, and hypertension are other conditions which may be treated with the compounds of the invention.

The above compounds are also characterized by high cell differentiation activity. Thus, these compounds also provide therapeutic agents for the treatment of psoriasis, or as an anti-cancer agent, especially against leukemia, colon cancer, breast cancer and prostate cancer. The compounds may be present in a composition to

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